Pasture as a Treatment System for

High Rate Application of Effluent.

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by
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Submitted in fulfillment of the requirements for the degree of Master of Agricultural Science.

graduating 1986

UNIVERSITY OF TASMANIA
HOBART

March 1985

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university, and to the best of my knowledge and belief, the thesis contains no copy or paraphrase of material previously published or written by another person, except when due reference is made in the text of the thesis.

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March 1985

Acknowledgements

I am very much indebted to Mr R.J. Cooper for help with system design and for valuable advice and assistance throughout the trial.

Funding for this project was provided by the Australian Pig Industry Research Committee.

Thanks are due to Cressy Research Station staff in particular Mr M. Fenton and Mr D. Kemp for technical assistance throughout the trial. Departmental officers at Mt. Pleasant Laboratories also gave valuable assistance with analysis of soil and effluent samples.

Appreciation is extended to Dr. A. Bray my supervisor in this trial.

Finally thanks to Miss K. Keskeridis for the typing and presentation of this thesis.

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1. SUMMARY

The basic aim of this project was to study the effectiveness of pasture as an aerobic treatment system for high rate piggery effluent application. Two management systems were compared. The first was year round application of effluent and the second employed separation of the effluent into particulate matter and supernatant then application of the sludge to pasture and storage of the supernatant during those months where the pasture cannot accept extra hydraulic loading. The stored supernatant was applied to pasture during the summer months when the soil water levels were low.

Separating out the high BOD containing solids components of the effluent before storage considerably reduced the oxidation pond area required. An above ground settling tank was easy to operate and after 24 hours settling the tank produced a supernatant with a total solids content of 1172 mg/l and a sludge of 9993mg/l total solids.

An oxidation pond was chosen to store the supernatant to keep odour problems at a minimum. The pond worked well with the low turbidity effluent allowing good light penetration resulting in dense algal growth and thus producing an aerobic layer that reduced odour. Large losses of water and nutrients occurred from the pond due to evaporation, seepage, losses in gases and fixation by the clay forming the bottom and walls of the pond.

These losses may have been compounded by difficulties in obtaining representative samples from an unmixed pond.

Soil on the effluent treated plots showed a larger increase in phosphorus content than potassium which would reflect the higher phosphorus levels in the effluent applied.

Pasture growth was not adversely affected by the high application rates. Pasture growth was greater on the effluent treated plots than the control plots during summer due largely to the irrigation effect.

Acceptance of effluent soiled pasture by sheep was poor when new sheep were introduced, however, acceptance increased with time after introduction.

Runoff was measured by draining the .45 hectare plots with levy banks and surface drains to a dumping tank situated in a ditch at the base of each plot. The number of dumps were automatically recorded and surface water samples taken daily during periods of runoff. Runoff was higher in 1981 which had a higher rainfall than 1982, 604mm compared to 453mm. Total runoff on the stored plots was 48% and 46% of the runoff on the fresh plots in 1981 and 1982 respectively. Even the stored treatment showed a large increase in runoff over the control plots due to extra hydraulic loading onto saturated soil during the winter months.

The ability of pasture to filter nutrients was very high. Approximately 1.3% of the BOD, 4.2% of the nitrogen, .8% of the phosphorus and 1.3% of the potassium applied to the stored plots was lost in runoff. However the quality of the runoff was not good enough for direct discharge into streams.

Drainage pipes were laid in the plots at a depth of 30cm. Pollutants in the drainage water were generally in low concentrations.

Runoff predicted by a water balance model WBAL3 (Rosenthal *et al*, 1976) was compared to runoff actually measured for each plot. The model accurately predicted the weeks in which runoff occurred. It also satisfactorily predicted the volumes of runoff although it showed a tendency to overestimate. The model can also be used to determine when and how much effluent irrigation could be applied throughout the year without causing increased runoff and therefore has a place as a management aid for high rate effluent application.

2. LITERATURE REVIEW

Introduction

Prior to World War II organic fertilizers played an important part in crop nutrition. Interest in organic fertilizers by farmers and researchers then decreased due to the advent of cheap inorganic fertilizers which had the advantage of ease of spreading and adjustable time of application to suit plant needs rather than disposal needs.

Also in post war years the trend to intensively house animals in large numbers increased. This led to large importation of feedstuffs onto the farm thus upsetting the nutrient balance between grass and crops produced on the farm and returned to the farm as manure. As far back as 1962 (Eby 1962) it was noted that larger amounts of manure were being spread on progressively smaller amounts of land due to intensification.

During the 1970's an increasing public awareness of pollution together with the increasing potential of large intensive animal units to cause pollution led to a concentrated research effort into the treatment of pig wastes. Many systems in use for municipal waste treatment or designed to produce a usable product such as methane were tested. They generally suffered from high expense and often produced a final sludge that still had to be disposed of onto land.

Under high application rates such as those studied in this project the pasture soil matrix can be viewed as an aerobic treatment system. The aim is to assimilate the nutrients in the waste with minimum damage to the environment rather than maximum utilization of the waste nutrients for grass or crop production. Aerobic treatment systems produce biologically stable end products and do not generate the offensive odours associated with anaerobic breakdown. Although the rate of application used in this trial, approximately 200 pigs per hectare, exceeds the pastures requirement for nutrients it is still within the range of application rates used in practice. Lee (1978) reported the case of Mayfair farms a very large highly intensified piggery housing 25,000 pigs producing 2.3 million litres of effluent a week. The construction of a freeway reduced the available disposal area by 20 hectares forcing them to spread the treated effluent on only 40 hectares of hilly grazing land.

Potential treatment mechanisms in the soil are many. They include biological oxidation, ion exchange, chemical precipitation, adsorption, and assimilation into growing plants and animals. The biological, physical and chemical processes in a soil provide a treatment of wastes that incorporates the factors and components of present day biological and advanced waste treatment methods for municipal and industrial wastes (Loehr. 1974).

However unlike the more expensive and sophisticated methods of effluent treatment the performance characteristics of pasture disposal are difficult to quantify. The ability of a given area of land to cope with the hydraulic loading of a given number of animals depends on the dilution rate, precipitation, evaporation, transpiration, crop and soil characteristics, slope and time of application. The ability of the system to cope with the chemical loading is determined by the crop requirements, whether or not nutrients are removed from the disposal area such as in hay or silage, initial nutrient status of the soil, the ability of the soil to fix nutrients level of pre-treatment if any detention time. Therefore it is impossible to give general guidelines such as 500 kg of nitrogen per hectare that cover all situations. Guidelines for maximum amounts of effluent that can be applied can only be given realistically on a regional basis and preferably on an individual farm basis. Information on management of waste for high rate disposal however is needed to form a basis for these recommendations.

A principle factor governing the effluent loading rates of all treatment systems is detention time. With aerobic pasture treatment maximum degradation is possible when detention time in the soil pasture matrix is at a maximum. Hydraulic loading from effluent and rainfall have a major effect on detention time as nutrients are leached and surface runoff occurs when the soil is saturated. Storage of effluent may be required to avoid excess hydraulic loading and its associated problems during certain times of the year.

A water balance model Watbal developed by the Queensland Department of Primary Industry (Rosenthal et al 1976) was used to predict runoff from each plot taking into account many of the factors affecting hydraulic loading listed above. These predicted figures were then compared with the actual volumes of runoff recorded to determine whether the water balance model could be used as the basis for recommendations for the timing and amount of effluent that could be applied to pasture.

Pasture will easily accept levels of effluent application to satisfy its nutrient requirements, however, when disposal rates are applied a high degree of management is required to achieve high purification rates. A knowledge of the complex interdependent processes taking place in the system are necessary in order to maximize those processes which are environmentally acceptable such as evapotranspiration, denitrification, volatilization and carbon dioxide production and to minimize those which result in pollution of air, surface water and ground water.

Detrimental effects of nutrient enrichment of the soil

In the short term, 10 to 20 years, the nitrogen content of pig slurry will limit the amounts of effluent that can be applied to pasture. However in the longer term other nutrients such as phosphate and potassi~~um~~ may limit application rates as levels of these nutrients fixed in the soil reach saturation (Vetter 1980). The time taken to reach this stage depends on the soil's initial nutrient status and type.

Excess nitrogen can produce lodging in cereals, decreases in starch (potatoes) and sugar content (sugar beets) (Smilde 1980). These effects limit the usefulness of crops other than forage crops for the disposal of high rates of effluent. Excess nitrogen can also lead to increased nitrate levels in plants and groundwater.

There are many factors that influence the susceptibility of animals to nitrate poisoning e.g. age, breed, nutritional status. Due to these variables the safe upper limit of 1.5 percent KNO_3 (dry weight basis) in the total ration must be interpreted with caution (Willoughby 1971). Poisoning by comparison, is common when the total ration contains 3 to 7 percent KNO_3 (Jubb 1970). Drinking water sources containing 45 to 100 ppm nitrate are considered safe for farm livestock (Willoughby 1971). Deaths from nitrate poisoning have been reported with concentrations usually above 712 mg/1 NO_3 in the drinking water (Jubb 1970). 10 ppm is the upper limit set by most authorities for potable water.

Excess K in herbage is associated with deficiencies of sodium, calcium and magnesium and the consumption of such herbage often gives rise to hypomagnesaemia (O'Callaghan 1973). This is more a problem with cattle than pig slurry because of the higher potassium content in cattle slurry (Collins 1980). The risk of hypomagnesaemia may be ameliorated by supplementation of the diet with magnesium but levels of K in excess of 3% are associated with more general mineral imbalances in the animal (O'Callaghan 1973).

Copper toxicity is of concern if copper is fed as a feed supplement in pig rations and high rates are applied to pasture. (O'Callaghan et al 1973)

Pollution of water resources from surface and groundwater can also lead to an oxygen demand which exceeds that which can be supplied by the water resources to completely degrade the organic matter. Enrichment of the nutrient status of the water may also lead to eutrophication or luxuriant growth of plant life (Littlejohn 1974).

Application of effluent to grassland

Pasture has a number of advantages over cropped land for high rate effluent application.

(1) It provides a groundcover all year round so that water and wind erosion transport a minimum amount of nutrients away from the treatment area.

(2) General losses of nitrate through leaching are smaller for grassland than from arable soils (Tunney 1980).

(3) Grassland can accept very large amounts of slurry before growth is inhibited (Dulthion 1980).

(4) The optimal amounts of slurry increase from least for cereals to most for grassland with root crops being intermediate (Vettor 1980).

(5) Grass is capable of removing more nutrients than other crops. Cooke (1972) gave nutrient removal rates of 250 Kg N/ha, 30 Kg P/ha, 250 Kg K/ha and stated that nutrient removal or uptake may be increased by increasing the amount of N applied.

Multiple cropping of pasture for hay and silage is preferable to grazing as a high proportion of nutrients are recycled under a grazing system rather than removed (Tunney 1980).

It is normal to recommend that at least 6 weeks should elapse between spreading manure and cutting grass, to avoid palatability problems as well as to enable manures to be adequately broken down (O'Callaghan 1973).

Application rates to prevent pollution

Sandiford (1984) stated that the desired standards of environmental quality tend to be politically determined. Some minimum standard must be set on health grounds, but more stringent standards may depend on pressure group bargaining between polluters, on the one hand, concerned with costs of abatement, and members of the public, on the other hand who perceive a deterioration in environmental quality.

Pollock and O'Callaghan (1975) based recommendations on application of livestock wastes on two principles.

(1) Slurry should be applied to satisfy, but not exceed, an existing soil moisture deficit, so that all liquid is retained within the soil matrix, and organic matter within the slurry is broken down by soil organisms.

(2) The total available nutrients applied in a season should not exceed the amount that can be removed in the crop to which it is applied in that season.

The second principle above led O'Callaghan et al (1973) to recommend 500 Kg N as a maximum level for pasture based on uptake of inorganic nitrogen. They did not take into account the large losses that can be expected from organic applications, the differences in uptake between organic and inorganic fertilizers is discussed in a latter section. This recommendation has been taken up by the Agricultural Research Council in Britain (A.R.C. 1976) and has received some acceptance as a guideline in Australia (Hilliard and Pearce 1978).

The impact of a given amount of animal wastes spread on land on water quality depends on a number of factors such as soil type, slope, rainfall before and after application, geology of the area, proximity to ground and surface water courses and time of year. In other words the technical relationships between dose and response are very complex and largely unknown (Sandiford 1984).

Another problem in basing recommendations on nutrient application rates is the variability in effluent. Difficulties in obtaining representative samples lead to large variability associated with poor repeatability in sample analysis (Hilliard and Pearce 1978). Lecomte (1980) and Wallingford et al (1975) found slurries to be extremely heterogeneous and suggested that the extreme variability necessitated complete chemical analysis of the waste before disposal. Work done with animals in metabolism crates has shown that differences in chemical composition occur on a daily basis for the same animal as well as for different animals fed the same diet, differences also occur with different feeds and age and condition of the pig (Littlejohn 1974).

O'Callaghan *et al* (1973) concluded that of the two principles determining application rates, the nutrient requirements of the crop grown and the permissible hydraulic loading rate, the former imposed a far more stringent limitation upon application rates than the hydraulic loading.

Pollock and O'Callaghan (1975) conducted a field trial which used the hydraulic loading constraint rather than the nutrient loading constraint to estimate the amount of liquid that could be applied. They found that calculations based upon a balance between rainfall and expected evapotranspiration to assess the maximum permissible hydraulic loading rate was convenient and suitable. Although the slurry was applied at higher levels than desirable for maximum grass growth the grass yielded quite well. The total efficiency of purification of the slurry amounted to approximately 98 percent and they did not find excessive levels of nitrate.

Sandiford (1984) concluded that pollution resulting from animal wastes is usually nonpoint source and possibly indirect. Its discovery may be very distant in time and space from the source. These together with the probable existence of other sources of pollutants, synergistic effects, multiple polluters and inadequate knowledge of the technical relationships involved make the apportionment of responsibility for the pollution very difficult.

Organic versus inorganic fertilizers

O'Callaghan <u>et al</u> (1973) based a recommendation of a maximum of 500 Kg N per hectare per annum on pasture responses to inorganic nitrogen applications. There is growing evidence however that responses to organic nutrients are lower than inorganic nutrients.

Dulthion (1980) found that between 30 and 50 percent of mineral nitrogen from manure was not effective in the first year or lost compared to 18 percent for fertilizer-N and concluded that 2 to 2.5 times the total N in fertilizer needs to be applied in manure nitrogen to get the same yield and quality of grass. Conflicting results have been found on the extent of nitrogen leaching from organic and inorganic nitrogen applications. Vetter (1980) found more leaching from organic manuring while Van de Maele and Cottenie (1980) found more leaching after mineral fertilization. The following estimates of the amount of nitrogen from pig manures available in the year of application have been made, 66% (Berryman 1968), 50% (Hobson and Robertson 1977), 50 to 75% (Anon 1976), 44 to 84% (Castle and Drysdale 1966), 50% (Tunney 1980). Nitrogen availability appears to be influenced by time of application, weather conditions, dry matter content of the slurry and whether it is incorporated into the soil or left on the surface.

Adam (1973) reported that slurry potassium was somewhat less than half as effective as fertilizer potassium in increasing the percentage potassium in the herbage at first cut. However, Kiely (1980) and Berryman (1968) report that all the potassium in slurry is available for plant growth during the first year because the potassium in animal manures is all water soluble.

Comparisons between phosphorus in animal manures and mineral fertilizers have also shown great variability. May and Martin (1966) indicated that phosphorus in animal manures is as effective as that in mineral fertilizers. Other workers have found that P in manures is only half as effective as fertilizer P in the year of application (Anon 1974; Hobson and Robertson 1977; Berryman 1968). While Adams (1973) found that in the short term slurry was only 10% as effective as fertilizer phosphorus in increasing the P content of herbage.

Nitrogen

The effect of nitrogen on the environment is a very important consideration for land disposal of effluent. Nitrogen undergoes transformations involving organic, inorganic and gaseous compounds when applied to pasture. An understanding of the processes involved is necessary to maximize environmentally acceptable loss of nitrogen if disposal rather than utilization is required.

Loehr (1974) state three reasons for concern over environmental quality with regard to nitrogen:-

(a) adverse health effects that may occur when the nitrate in drinking water exceeds acceptable limits or when nitrates and nitrites in forages and leafy vegetables reach toxic levels,

(b) oxygen demand caused by the oxidation of reduced nitrogen compounds in surface waters,

(c) eutrophication of surface waters stimulated by an abundance of nitrogen.

Nitrogen is present in animal manures in the ammonium form (NH_4^+) and in organic combination. The relative proportions of the two forms vary according to conditions of handling and storage (Bhat *et al* 1980).

The first microbial transformation is the ammonification of organic nitrogen (Loehr 1977).

$$\text{ORGANIC NITROGEN} \xrightarrow[\text{(heterotrophs)}]{\text{ammonification}} NH_3 \xrightarrow[\text{hydrolysis}]{H_2O} NH_4^+ + OH^-$$

Free ammonia (NH_3) is very volatile and much of it volatilizes into the air (Papanos and Brown 1950).

The literature contains many references to high nitrogen losses due to ammonia volatilization which is an environmentally acceptable form of applied nitrogen loss. Koelliker and Miner (1971) report nitrogen losses of 15 to 30 percent between the lagoon and land surface during sprinkling. The following losses of ammonia applied in slurry during the first three days after application have been reported Sherwood (1980) 62%, Laver et al (1976) 85%, Salter and Schollenberger (1939) 50% and Stewart (1970) 80%.

Drying in response to evaporative conditions drives the process of NH_3 volatilization (Laver et al 1976; Stewart 1970). In areas where land area is limited relative to animal population NH_3 volatilization may decrease the potential for leaching of nitrate into ground water (Laver et al 1976).

Ammonium ions are positively charged and move slowly with the soil water because of the attractive forces between the ammonium ions and negatively charged clay and organic colloids. As long as nitrogen stays in the ammonium form the possibility of nitrogen loss by leaching is low. Agricultural soils with a high cation exchange capacity can absorb significant amounts of ammonia, though the absorption is reversible under aerobic conditions (Loehr 1974).

Under aerobic conditions ammonium nitrogen can be microbially oxidized to nitrate by the autotrophic organisms Nitrosomonas and Nitrobacter, this is termed nitrification (Loehr 1977).

$$NH_4^+ \xrightarrow{\text{(Nitrosomonas)}} NO_2^- \xrightarrow{\text{(Nitrobacter)}} NO_3^-$$

The nitrification rate in soil is affected by rate of nitrogen application, temperature, soil moisture and organic C levels (Alexander 1965; Loehr 1974; Reddy and Graetz 1981).

Campbell et al 1974 found that 70 to 90% of the nitrate produced in surface soil resulted from wetting and drying through favoured conditions of microbial oxidation.

Nitrates pose a serious threat to groundwater pollution as they are soluble and can be leached out of the root zone of crops and into the ground water.

Both nitrate and ammonium losses from the soil can result from uptake by plants. Ninety percent of nitrogen absorbed by plants is in the nitrate form. Excessive nitrogen can result in excess non protein nitrogen in forage plants (Smith 1967).

Denitrification is another process which results in an environmentally acceptable loss of nitrogen. Denitrifying organisms reduce nitrate and nitrite to nitrogen oxides or nitrogen gas which returns to the atmosphere.

Patrick and Mikkelsen (1971) stated that denitrification is the major mechanism of nitrogen loss in waterlogged and poorly aerated soils in which fluctuating aerobic and anaerobic conditions occur. They found denitrification losses of 50% or more to be common.

Denitrification rates are affected by oxygen levels, moisture content and temperature. Van Schreven (1963) found that the soil as a whole does not have to be anaerobic before denitrification takes place, there are often pockets or zones in the soil which are oxygen depleted. The process is accentuated by the application of farm wastes because of the oxygen demand imposed (Burford 1976). High moisture content is necessary for denitrification. Bremner and Shaw (1958) found that the critical soil moisture content for denitrification to occur is 75 percent of water-holding-capacity. Denitrification proceeds at a slower rate as temperatures fall however Sherwood (1980) found considerable denitrification in pig slurry even at 5°C.

Denitrification organisms are known to be present at considerable depths in soil (Stevenson and Wagner 1970) and may be an important mechanism for nitrate reduction in ground water. Meek _et al_ (1969) concluded that much of the nitrate leached into subsoil in irrigation waters was lost through denitrification. Stewart et al (1967) found that nitrate levels in soil under feedlots decreased sharply with increasingly depth and concluded that the decrease was due to denitrification.

Management of biological denitrification is possible by successive cycles of waste application and resting. The anaerobic conditions created during waste application would result in a significant loss of nitrate produced by oxidation of ammonium during the aerobic cycle (Stevenson and Wagner 1970; Koelliker and Miner 1969; Loehr 1974).

Therefore two acceptable forms of nitrogen loss ammonia volatilization and denitrification can be driven by successive wetting and drying cycles which suggests regular applications of small volumes of effluent to the disposal area rather than applications of large volumes at longer intervals.

In summary organic nitrogen applied to pasture has a number of possible fates. Environmentally acceptable losses include immobilization in organic forms such as microbial cells, harvested as protein in crops, lost to the atmosphere through the process of ammonia volatilization and denitification and adsorption onto clay and organic particles. Unacceptable losses include leaching of nitrate into groundwater and nitrogen loss in surface runoff.

Phosphorus

If erosion can be prevented, the soil is an exceedingly good retainer of phosphorus regardless of its source (Viets 1971). Australian soils are generally low in phosphorus and many are capable of prolonged heavy application of phosphorus before their adsorptive capacity is reached.

Organic forms of phosphate are not available to the crop directly but become available as orthophosphate following organic matter decomposition (Patrick and Mikkelson 1971). Pig effluent contains a mixture of organic and inorganic forms of phosphorus. After inorganic phosphorus is added to soils extractable levels will decline with time. However when animals' wastes are applied to soils mineralization of the organic phosphorus occurs and extractable phosphorus levels may increase. Therefore both mineralization and immobilization occur simultaneously with extractable phosphorus levels equalling the net or sum of both processes (Sikora and Corey 1976; Lecomte 1980).

Phosphorus immobilization in the soil is related to the mineral constituents of the soil. In acid soils fixation is caused by the formation of insoluble iron and aluminium compounds. In alkaline soils the fixation is due to insoluble calcium compounds (Loehr 1974). Phosphorus reacts with clay in several ways. One reaction is the replacement of hydroxyl ions in the surface layer of clay minerals, there is also evidence of phosphorus exchange with silicate ions in clay. It also reacts with iron and aluminium ions released from the surface decomposition of clay to form insoluble aluminium and iron phosphates (Patrick and Nikkelsen 1971).

More phosphate moves downwards into deeper soil layers on sandy soils than on heavier soils (Vetter 1980) because of the lower adsorption and reactive capacities of sandy soil. Olsen and Watanabe (1970) reported that the pollution hazard from phosphorus in solution was about eight times greater for a sandy soil than for clay with the same supply of available soil phosphorus. Goodrich and Monke (1971) found that sandy loam with its higher clay content adsorbed up to four times as much phosphate as sand.

Since phosphorus is largely adsorbed by soil it may move into underground aquifers only when the adsorptive capacity of the soil for phosphorus is reached (Goodrich and Monke 1971). Each soil has a phosphorus adsorptive capacity which can be exceeded by prolonged high phosphorus application. The phosphorus adsorptive capacity may not be exceeded for decades or centuries in soils having a high clay content (Loehr 1974).

The removal of phosphorus from the soil is almost entirely due to plant uptake, with some losses occurring in land runoff (Cooke 1972). Gaseous losses of phosphorus do not occur naturally (Loehr 1977). Eutrophication (accumulation of nutrients) in surface water is largely due to increased phosphate supplies since this is the most important growth-restricting minimum factor (Finck 1982). This may be a problem if phosphorus contained in manure does not come into contact with soil but is washed off into watercourses (O'Callaghan _et al_ 1973).

Potassium

Potassium can undergo a fairly intense fixation process (inside the clay mineral lattices) particularly in clayey or loamy soils. It would be temporarily removed from the soils stock of exchangable potassium (Lecomte 1980). The amount of fixation depends upon the charge densities of the clay present in the soil. Clays with high charge density on their layers are held together more tightly after K has been trapped between them, hence, clays with high lattice charge fix the most potassium. Because of high potassium fixation it is not practical to build up available potassium in some soils.

All the potassium applied is likely to contribute towards feeding the plant sooner or later (Lecomte 1980; Beckett 1971; Adams 1973).

Potassium is effectively removed from the soil by crops such as grass, potatoes and sugar beet (Cooke 1972). Leaching of soluble potassium salts to watercourses is not associated with spoilage through eutrophication. However, excessive potassium loading on to pasture may result in induced mineral imbalances in grazing stock, particularly hypomagnesaemia.

Oxidation Ponds

Oxidation ponds have two major advantages in the storage and treatment of animal waste.

(1) They are inexpensive compared to other aerobic methods which require considerable energy input to raise the oxygen concentration of the waste.

(2) They do not give rise to malodors characteristic of anaerobic systems if operated correctly.

In practice however they have often proved unsatisfactory in the treatment of animal waste (Hart and Turner 1965; Hobson and Robertson 1977; McKinney 1970). The principle reason for this is that oxidation ponds are well suited to dilute low BOD_5 wastes whereas animal wastes are generally concentrated liquids with a high oxygen requirement.

In an oxidation pond bacteria and algae operate in a symbiotic mode to stabilize organic wastewaters (White 1977). Heterotrophic bacteria are responsible for the stabilization of the organic matter in the pond. As the soluble organic wastes entering the pond and releasing from the bottom sludges through anaerobic breakdown are metabolized by the bacteria, end products such as carbon dioxide, ammonium and nitrate ions, and phosphate ions become available for growth of algae. As the autotrophic algae produce new protoplasm, oxygen is an end product and can be used by heterotrophic bacteria (Loehr 1974).

A balance between the two organisms must be maintained otherwise odours will arise and a poor quality effluent will be produced. The algae in the surface layers maintain an aerobic zone and reduce odours. This imposes a number of constraints on pond design.

Since sunlight is essential for oxygen production by algae, depth of water and turbidity are extremely important in this sort of lagoon. Depth where algae grow profusely is limited to about 50 cm, which is the maximum light penetration for most lagoon waters (White 1977). Oxidation ponds are therefore designed with a shallow water depth generally 1-1.5 metres (Loehr 1974; White 1977). Preliminary solids separation will reduce the BOD_5 level and turbidity of the effluent thus increasing its suitability for oxidation pond storage and treatment.

Another important factor requiring lagoons to be designed with a large surface area to volume ratio is oxygen supply and mixing. Net oxygen transferred in the pond is the sum of the algal oxygen production and the quantity added or lost from the atmosphere. The oxygen produced by algae is contained in the upper part of the pond. This must be mixed to levels where it can be utilized by the bacteria. Wind and wave action are the major mechanisms for mixing of nutrients and oxygen whereas diffusion from areas of high concentration to areas of low concentration is negligible.

The large surface area requirement may result in high evaporative losses and combined with a requirement for low turbidity may require the addition of water to maintain depth particularly during summer.

Although oxidation ponds stabilize and oxidize organic wastes they tend to recycle nutrients rather than remove them. The organic components are converted to the unobnoxious form of algal protoplasm. If BOD removal is the primary aim then provision must be made for carbon removal by methane production or removal of algal cells from the effluent (Loehr 1974).

A major factor determining the maximum BOD loading of the pond is the detention time. If the pond is to only accept effluent for a portion of the year and then store it until it can be disposed of then BOD loadings can be higher than if it is to be used on a continuous flow basis. Design loadings for continuous flow systems range from 56 Kg BOD/hectare/day (Loehr 1974) to 112 Kg BOD/hectare/day for tropical and subtropical climates to obtain BOD removal of greater than 90% (Canter et at, 1968). Although studies on oxidation ponds in Texas showed that loadings could be 168-224 Kg BOD/hectare/day providing the effluents were used for irrigation or diluted with adequate stream flow (Gloyna and Hermann 1956). For animal wastes that have not undergone any pretreatment or separation to reduce the BOD content the large pond area required may be prohibitive.

3. MATERIALS AND METHODS

System Design

The layout of the land disposal system is shown in Figure 1. The basic design of the storage system was developed by 'Fowler England and Newton' Hobart, a firm of consulting charted engineers and town planners.

The following basic considerations were taken into account when designing the system

(i) Capital and operating costs should be kept as low as practically possible and therefore a storage system was required rather than a treatment system.

(ii) Storage times should be kept to a minimum and the storage facility used only when necessary and start and end each cycle of usage in the empty condition.

(iii) Aerobic storage is required to reduce odour problems and because biologically it is undesirable to pump high volumes of anaerobic effluent onto an aerobic pasture system.

(iv) The observation from previous high application rate trials carried out at Cressy that the different positions of the sprinkler could be determined by examining the grass roots for deposition of solids. Without exception solids deposition was at a maximum close to the sprinkler position. This deposition occurred even in the pasture damaged areas which had long periods of effluent immersion. Hence the solids tend to lie where the pump pressure deposits them and are not moved later by surface runoff. The lighter solids can be expected to be transported but it was indicated that solids loading might be possible at a higher concentration than that naturally occurring in the effluent. That meant that it might be possible to deposit sludge without pollution at times when lack of soil absorption prevents continuous liquid dosing.

Costs

23,000 litre concrete tank (2.7m high * 3.4m diameter)	$ 930
290 litre upright freezer	$ 450
4 travelling effluent spreaders	$ 2,400
6 flushing buckets (508mm * 765mm * 800mm)	$ 1,000
6 counters & sampling tanks	$ 200
750 m fencing	$ 1,000
Polythene piping fittings & installation	$ 3,600
Installation of ponds drains and earthworks	$ 3,300
	$ 12,880

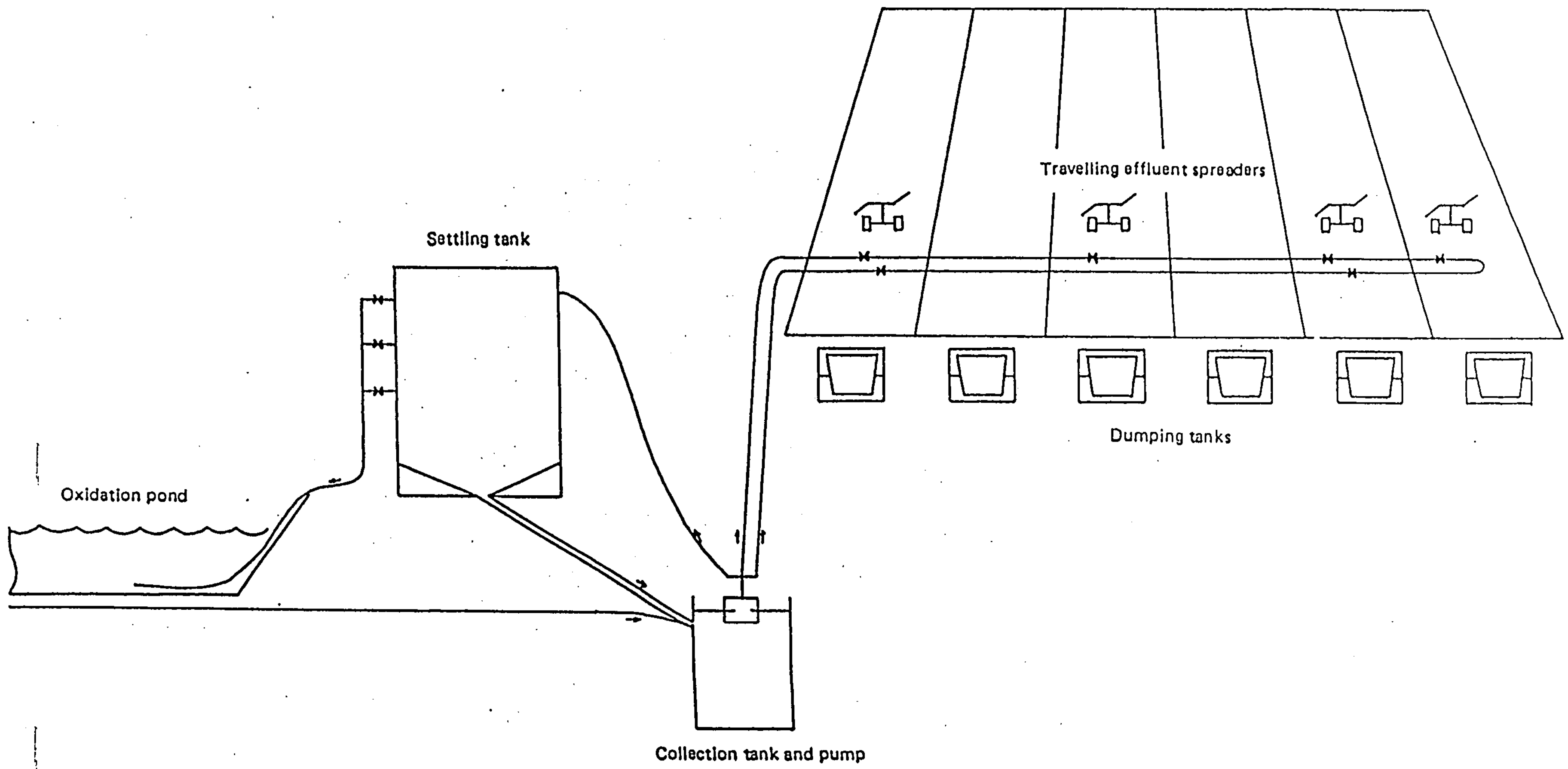

FIGURE 1 : LAYOUT OF SYSTEM

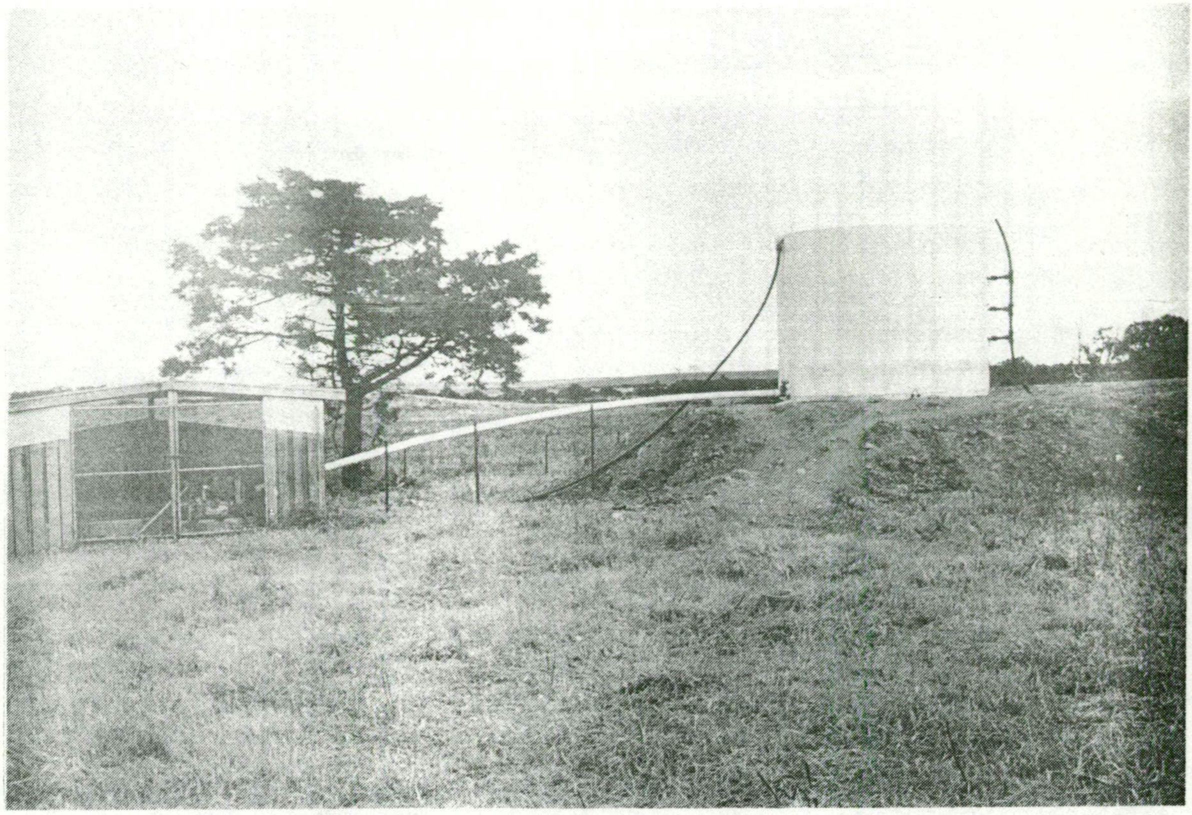

PLATE 1. COLLECTION TANK, PUMP AND SETTLING TANK

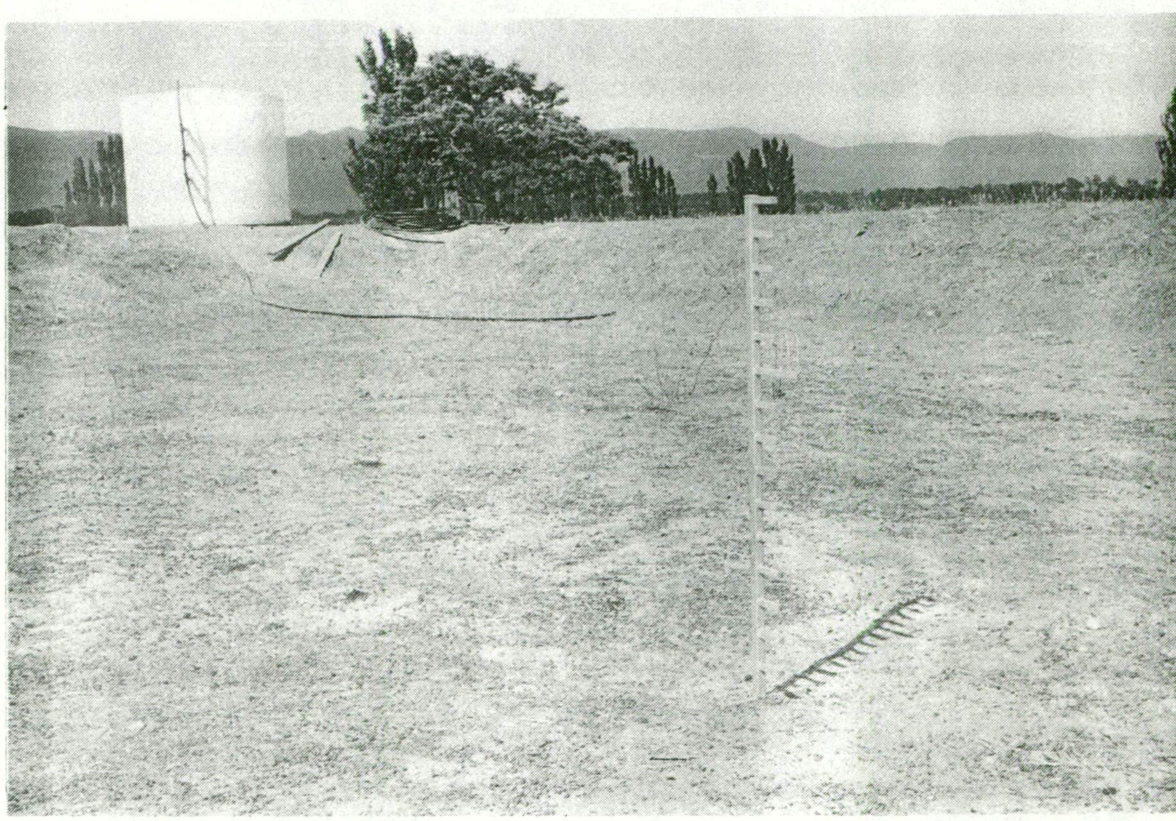

PLATE 2. OXIDATION POND

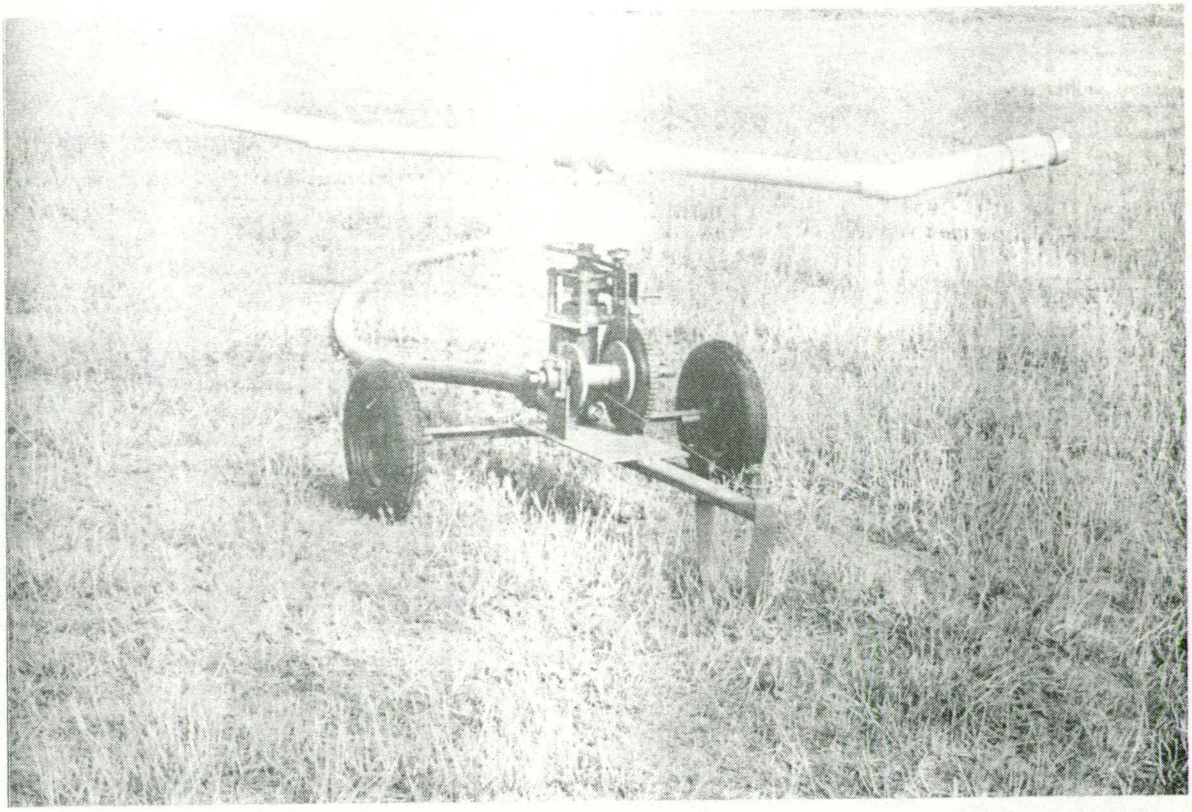

PLATE 3. TRAVELLING EFFLUENT SPREADER

PLATE 4. TRIAL PLOTS

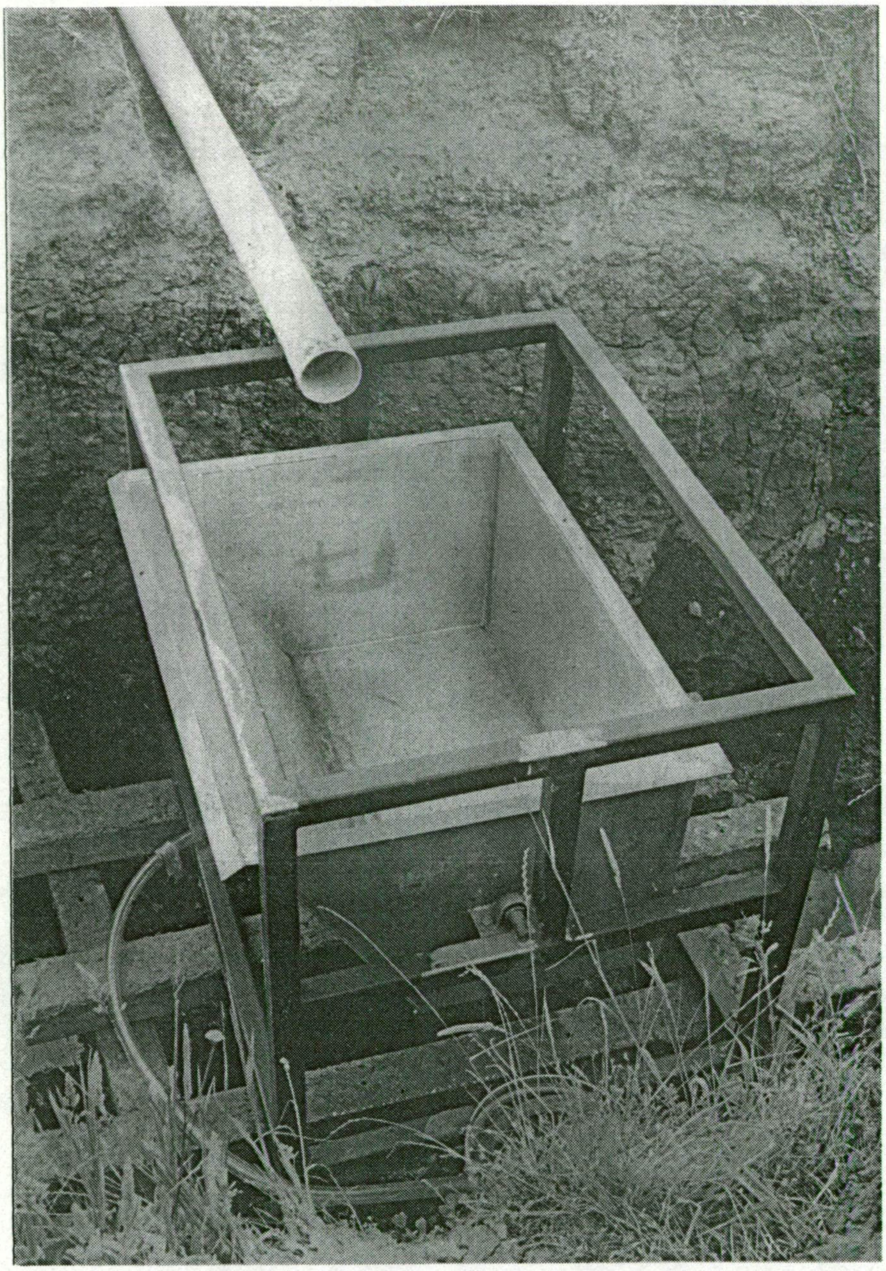

PLATE 5. DUMPING TANK

Photography R. Cooper

Effluent from the 45 sow piggery is gravity fed into a collection sump (Plate 1). The sump is equipped with an agitator with an extended shaft driven by a V-belt and a 0.74 kw electric motor. This keeps the material in suspension prior to and during pumping. A float switch operates a self driving pump that has a positive displacement and is of a rotating cavity type. It is powered by a 2.23 kw electric motor. Hours of pump operation were recorded by a 'Seimens' hour recorder. The slurry pump delivers effluent via a 50mm irrigation line to either the settling tank or via one of two lines to travelling irrigators in the treatment plots.

The storage system itself consisted of an above ground settling tank and an oxidation pond (Plate 2). When the storage system was in operation effluent was pumped from the collection sump into the top of the settling tank and allowed to settle for 24 hours. The 23,000 litre concrete settling tank was designed to separate the effluent into supernatant and heavy slurry fractions. The supernatant was drained off into the oxidation pond through the outlets on the side of the tank and the remaining sludge fraction was then agitated with a propeller driven by a 1.5kw electric motor and then drawn off from an outlet at the centre of the tank's conical base back to the collection sump for distribution to the plots.

The oxidation pond was constructed of compacted clay and had a surface area of 2400m^2 and a depth of 1 meter. It was designed to cope with a daily loading of 15.75 kg BOD which is equivalent to 65.6 kg/day/hectare without odour problems.

Treatment Plots

A gently sloping area in close proximity to the pig unit was selected as the treatment area. A survey of this area was conducted on a 10 meter grid spacing and the result fed into the CSIRO development Contour program available as a public file on CSIRONET to produce the contour map shown in Figure 2.

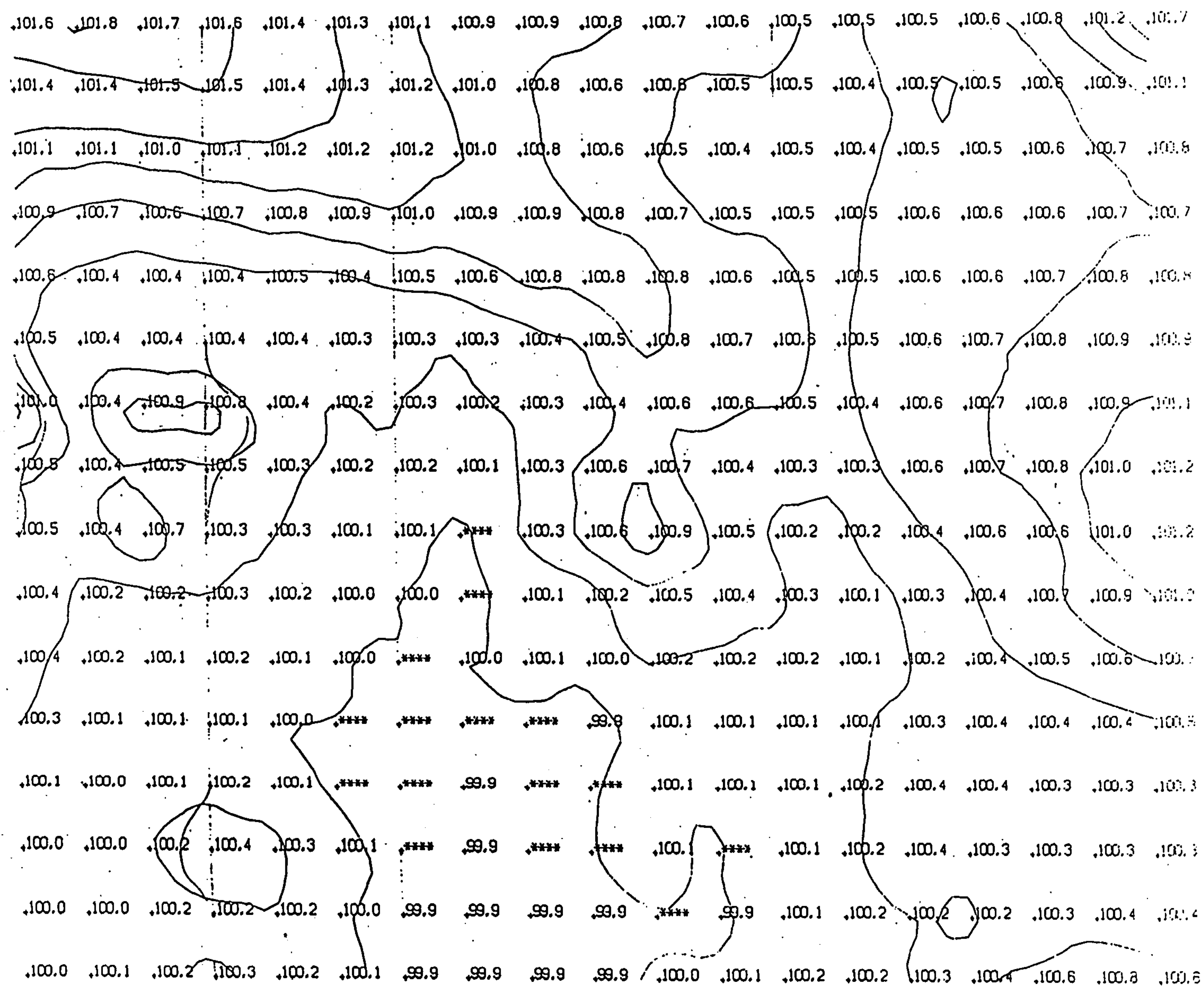

FIGURE 2 : CONTOUR MAP OF DISPOSAL AREA

This map was then used to design a series of check banks and open field drains so that runoff from the six .45 hectare treatment plots could be collected without any surface water movement between plots (Plate 4).

The plots were 150 x 30 metres to facilitate the even spread of effluent using travelling irrigators (Plate 3) which had a distribution diameter of 20-25 metres.

Surface water from each plot was channeled into 355 litre dumping tanks (Plate 5) installed in a 2 metre deep trench excavated along the western boundary of the plots.

A counter was attached to each dumping tank and the number of dumps was recorded daily. A litre sample of runoff water from each plot was collected daily during periods of runoff and immediately frozen. These samples were latter pooled into a monthly sample for each plot for analysis.

Perforated drainage pipe was laid from the trench 30 metres into the trial plots at a depth of 30 cm. A container was attached to the end of the pipe to collect drainage water flowing in the pipe. A litre sample was taken and frozen daily for each plot during periods of drain flow.

A pump driven by a 1.1 Kw electric motor and operated by float switches was used to drain the pit.

Sampling of runoff and effluent

A 250 ml container was attached to the front of each dumping tank. This container filled each time the dumping tank emptied. A plastic tube attached to the bottom of the container drained the sample into a 20 litre plastic drum. A litre sample was taken from this drum daily and the drum then emptied. Samples of fresh effluent were taken from the collection sump after the effluent had been agitated to ensure a homogeneous mix. These samples were taken monthly.

Effluent Application

The following three treatments were allocated two .45 hectare plots each.

(1) **Control** : These plots received no effluent and were used to assess the background contamination of stormwater runoff resulting from grazing sheep and previous fertilizer applications.

(2) **Fresh** : These plots received half of the waste output of the 45 sow piggery on a daily basis throughout the year. This treatment was used as a comparison with the storage system and to determine the levels of stormwater pollution from high rates of effluent application throughout the year.

(3) **Stored** : These plots received three different application regimes.

(a) During those periods of the year where the soil was saturated the effluent was put through the storage system and only the sludge fraction applied to the pasture.

(b) During the summer period the stored supernatant from the oxidation pond and half the piggery's output of fresh effluent was applied to the plots.

(c) For the remainder of the year fresh effluent was applied daily.

Soil samples were taken before commencement and after completion of the project. A sample was taken from each quarter of each plot. The sample was a composite of 20 cores (1 cm diameter, 75 mm deep). Each sample was analysed for Water pH, cond.Ms, phosphorus and potassium.

The volume of effluent applied to each plot and the volume of runoff water were recorded daily.

Analysis carried out on effluent and water samples were:-

- nitrate nitrogen (Terrey 1966)
- total nitrogen, phosphorus and potassium (Williams and Twine 1967)
- pH, BOD, total solids, settleable solids (American Public Health Association 1969)

Meteorological data, soil temperatures, shade temperatures, rainfall and evaporation were recorded at the Cressy weather station.

A simulation model, WBAL3 (Rosenthal *et al* 1976) developed to perform water balance accounting was used to compare predicted runoff from the plots with the runoff actually recorded. The model required entry of the rainfall data, effluent applied, evaporation, soil and cropping details for each plot.

Candidates role

The candidate was responsible for the implementation of this project at all stages.

The following tasks were undertaken by the candidate

(1) Experimental design.

(2) Consultation with the firm 'Fowler, England and Newton' of Hobart on engineering aspects of the system.

(3) Development of specifications for construction of the dumping tanks, settling tank, oxidation pond, pipes and fittings.

(4) Supervision and participation in the implementation of the design including construction of the oxidation pond, ditches, drains and contour banks and the assembly of pumps pipes and irrigators.

(5) Supervision of sampling of effluent and surface and groundwater runoff.

(6) Pooling of samples and assistance with effluent sample analysis.

(7) Compilation and analysis of results.

4. RESULTS AND DISCUSSION

Oxidation Pond

Oxidation ponds require dilute wastes in order to keep the turbidity low and light penetration high (Hobson and Robertson 1977; Loehr 1974; Taiganides 1977; McKinney 1970). The solids content of waste going into the pond was very low due to the initial dilute waste and settling of the solids in the concrete settling tank. Also before commencing operation the lagoon was flooded to a depth of 15cm with fresh water.

The lagoon worked well as a storage system with very little odour problem except for a three week period at the start of the first year when the algae were in low concentration.

On emptying the lagoon the crust remaining on the bottom was only about 5mm deep and over approximately 30% of the area of the lagoon.

Table 1 gives the composition of the oxidation pond liquid before it was pumped to paddocks.

Biological oxygen demand was low as most of the carbon and nitrogen present in the original waste had been lost as gases or converted to algae and bacterial cells.

TABLE 1 : ANALYSIS OF OXIDATION POND LIQUID APPLIED TO PLOTS

DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
DECEMBER 1981	2	50	8.2	6.9	625	155.0	99.7	0	158
NOVEMBER-DECEMBER '82	2	66	8.2	6.25	540	184.7	140.3	0	162

The pH had risen to 8.2 which is within the optimum growth range for algae of 7 to 8.5 (McKinney 1970). Algae absorb carbon dioxide generated through bacterial metabolism and contained in the pond waters to produce more algal cells. The removal of carbon dioxide from pond waters results in an increase in pH which may rise to above 9.0 (Loehr 1974; McKinney 1970).

The solids component of the pond water was mainly present as algae with most of the original waste material broken down.

The increased concentrations of phosphorus and potassium were probably due to a reduction in pond volume.

No nitrate nitrogen was present and there had been losses of nitrogen resulting in lower total nitrogen concentrations.

In the order of 30 to 40 percent loss of pond volume occurred during the 3 month storage period. No make up water was added but this is often necessary in practice to maintain depth. Water loss occurred through two major mechanisms:-

(1) During the storage period no effluent was added and evaporation far exceeded rainfall as can be seen from the following table.

Table 2 : Evaporation and Rainfall during Storage (mm)

		October	November	December
1981	rainfall	60.4	31.4	23.5
	evaporation	115.2	127.8	182.4
	deficit	54.8	96.4	158.9
1982	rainfall	22.2	13.8	71.8
	evaporation	119.6	182.6	198.6
	deficit	97.4	168.8	126.8

Therefore considerable evaporation losses could be expected due to the high surface area to volume ratio.

(2) Losses also occur through seepage. The pond bottom and sides were composed of compacted clay. The amount of seepage permitted from oxidation ponds in the United States ranges from 2.5 to 6 mm per day between various States (Loehr 1974).

Considerable losses also occurred of the measured effluent constituents. Samples of supernatant added to the pond were not taken for analysis so an accurate estimate of the nutrient loss in the oxidation pond cannot be given. However as equal volumes of effluent were allocated to the stored and fresh treatments approximate values of nutrients entering the pond can be gained from the difference between nutrients applied to pasture as sludge and fresh effluent.

Table 3 : Estimated percentage loss of Components in effluent from oxidation pond storage

	BOD_5	N	P	K
1981	99	91	56	48
1982	94	93	74	50

A number of possible factors which contributed to the large percentage losses of effluent constituents, during storage are as follows:-

(1) Sampling error : The samples of oxidation pond water taken for analysis may underestimate the total nutrients in the pond. The oxidation pond could not be mixed prior to sampling and layering of nutrients may have occurred in the pond. Vanderholm (1975) showed losses of potassium in the supernatant of lagoons and holding ponds and high potassium contents in the bottom sludges indicating a process similar to phosphorus precipitationwas occurring with potassium.

(2) Leaching : Preul (1968) studied contaminants in groundwater near oxidation ponds with relatively high infiltration rates. The nitrogen in the pond percolation waters was found to be mainly ammonia

nitrogen, 1.0 to 20.0 mg/l with little nitrate, 0.1 - 0.5 mg/l. Phosphate concentrations were not significant ranging from 0.2 to 1.0 mg/l three meters from the edge of the ponds.

(3) BOD removal is accomplished through loss of carbon dioxide and methane and conversion of carbonaceous and nitrogenous material, to algae. Canter et al (1968) reported BOD removal rates of greater than 90% using oxidation ponds. Detention times for oxidation ponds vary from 5-7 days to several weeks (White 1977). Detention times of 3 months used in this project would allow most of the organic matter to be oxidised.

(4) A high percentage of the nitrogen entering the pond would be in the soluble ammoniacal form due to previous separation of the solids component. Losses through ammonia volatilization may occur. Mixing may allow oxidation to nitrate to occur in the upper portion of the pond followed by dentrification in the anaerobic bottom sludges. This may result in losses of nitrogen as nitrogen gas and gaseous nitrogen oxides.

(5) The floor and walls of the pond were composed of compacted clay. Because of the large surface area to volume ratio this presents a large area of clay

for reactions with phosphorus and potassium in the effluent.

Potassium can undergo a fairly intense fixation process inside clay mineral lattices (Lecomte 1980; Dinaver 1971; Beckett 1971). Phosphorus is readily adsorbed onto clay forming insoluble phosphorus compounds (Loehr 1974; Vanderholm 1975; Patrick and Nikklesen 1971).

Reddy and Graetz (1981) used a shallow reservoir with a marly clay loam bottom for PO_4-P removal from agricultural drainage effluent. About 70 and 76% of the flood water phosphate was removed under aerobic and anaerobic water column conditions respectively in 29 days.

Settling Tank

Solid floors are used in the piggery requiring large amounts of wash down water for cleaning which results in a relatively dilute slurry. The common practice of ;flushing effluent pits may also result in dilute slurries.

The settling tank worked very well as a device for separating a relatively high moisture content effluent into supernatant and sludge components in a 24 hour settling period. More efficient separation devices such as run down screens or centrifuges would produce solid and liquid components that would have to be handled separately. No blockages or pumping difficulties were encountered as the sludge was agitated before being gravity fed back to the pump for spreading onto the plots.

Table 5 gives the analysis of effluent at four depths in the tank after 24 hours settling. The depths given are in metres measured from the top of the tank. The samples were taken during the two periods of operation of the tank in 1981 and 1982.

The settling effect is shown clearly in the total solids. Total solids concentration remained fairly constant for depths of 0, .8 and 1.6 metres during both years with a large increase at the greatest depth in the tank.

Settleable solids showed an even more marked variation between the first three depths which again remained fairly constant and the deepest sample which contained virtually all the settleable solids. Oatway et al (1977) evaluated a large concrete tank (7.3 m x 7.3 m x 2.4 m) as a settling chamber for swine wastes. The tank performed well for 14 weeks before it became clogged with solids. It accepted manure with an average total solids content of 5.6 percent and discharged effluent at 1% total solids.

pH in both years showed a slight decrease in the sludge portion of the effluent.

Urine contains approximately 70, 40 and 50% respectively of the total nitrogen, phosphorus and potassium excreted (O'Callaghan et al 1973).

The concentration of phosphorus at the greatest depth was about three times that of the rest of the tank. This was to be expected because much of the phosphorus is organically bound and is not in the soluble orthophosphate form. Germon et al (1980) found that almost all the phosphorus was in the suspended solids fraction of the effluent.

Potassium was not influenced to any great extent by settling with only a slight increase at the greatest depth. Germon et al (1980) states that potassium is almost fully soluble and that therefore the greater part of the potassium will be in the aqueous phase.

Nitrate nitrogen was only present in small amounts. Mixing and pumping of fresh effluent to the settling tank would allow some of the nitrogen to be oxidised to the nitrate form. Nitrate nitrogen was higher in the solid portion of the effluent than the supernatant.

Total nitrogen like phosphorus did not show a large variation with depth due to settling. Nitrogen is present in soluble ammoniacal form as well as in the organic form in the solids. Oatway _et al_ (1977) found with settling tank studies on pig waste that nitrogen was influenced to a lesser extent by settling than was phosphorus or total solids.

TABLE 4 : ANALYSIS OF SLUDGE FROM SETTLING TANK APPLIED TO PLOTS

DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
JUNE-SEPTEMBER '81	4	8820	7.2	131	8087	310	142	1.2	971
JUNE-SEPTEMBER '81	4	12910	7.05	112	7776	396	202	2.3	1154

TABLE 5 : ANALYSIS OF EFFLUENT FROM 4 DEPTHS IN SETTLING TANK

DATE	DEPTH (meters)	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	N(NO_3) (ppm)	N(total) (ppm)
AUGUST 1981	0	2,200	7.84	LT 0.1	1,600	93	89	.1	510
	.8	3,250	7.9	1.0	1,550	93	87	.1	532
	1.6	2,700	8.1	1.0	2,050	97	85	.1	505
	2.4	16,200	7.0	175	10,100	310	100	1.5	726
AUGUST 1982	0	4,480	7.56	LT 0.1	1,409	74	94	.1	524
	.8	3,730	7.60	1.0	1,316	78	93	.1	517
	1.6	3,960	7.64	.1	1,449	72	93	.1	531
	2.4	15,900	6.85	150	9,885	237	105	3.0	696

TABLE 6 : ANALYSIS OF PIGGERY EFFLUENT APPLIED TO PLOTS

DATE	NUMBER OF SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
JANUARY-MARCH 1981	3	2530	8.1	35	4200	131	116	.1	768
APRIL-JUNE 1981	3	2350	8.1	40	3300	143	83	3	714
JULY-SEPTEMBER 1981	3	6370	8.4	33	2530	205	98	.05	785
OCTOBER-DECEMBER 1981	3	4970	7.2	72	7270	256	109	.1	880
JANUARY-MARCH 1982	3	4300	7.5	49	5460	240	106	.1	847
APRIL-JUNE 1982	3	3570	8.1	46	4160	176	88	.1	740
JULY-SEPTEMBER 1982	3	3930	7.3	83	6270	362	154	3	978
OCTOBER-DECEMBER 1982	3	3033	7.6	45	5800	358	152	.1	452

Soils

The soil profile was about 40 cm of loamy soil overlying about 20 cm of sandy clay and sandy clay loams with medium and heavy clay at about 60 cm.

The results of soil analysis taken before commencement and after completion of the trial are given in Table 7 for each plot.

Changes in soil pH were only slight over the period of the trial with no marked differences between treatments. The slight rise in pH in both treatments receiving effluent was probably due to the effluent itself being slightly alkaline with a range from 7.2 to 8.1. The slight change in pH should not have any effect on pasture growth. Lecomte (1980) found that incorporating animal effluent into the soil did not affect soil pH.

Conductivity showed marked rises in the plots receiving effluent with rises being less in the plots receiving stored effluent than in the fresh plots. The rise from .2 to .4 in the first control plot was probably a sampling effect although the second year of the trial was a dry year which could lead to increased conductivity on the non irrigated control plots. Buildup of soluble salts in soils after waste application has been implicated in reducing the fertility of soil by increasing soil salinity. Potassium is considered the specific soluble salt most responsible for increased soil salinity (Wallingford et al 1975).

The initial phosphorus levels of the soils in the treatment plots (130-210 ppm) were high for soils in this area. Normal levels are in the range 25-80 ppm. The normal practice at the Research Station is to apply 185 kg per hectare of superphosphate in the early Autumn. Also prior to 1973 the treatment area was used for effluent application during the winter months which may have left higher than normal residual phosphorus levels.

There was a large increase in phosphorus in both treatments receiving effluent. Rises in phosphorus were only slightly less for the stored plots compared to the fresh plot. The difference was probably due to losses of phosphorus in the storage system leading to reduced phosphorus levels being applied to the stored plots. High final levels of phosphorus in the range 660 to 828 ppm resulted from effluent application.

Sherwood (1980) found that after seven applications of slurry the phosphorus was mainly retained in the top 2.5 cm although a small amount had penetrated to the 10-15 cm zone. In this trial 7.5 cm soil cores were taken so it can be expected that most of the phosphorus was held in this layer.

Initial potassium levels in the plots varied from 197 to 381 ppm, however, unlike phosphorus these levels are average for the Cressy area. The rises in soil potassium levels with effluent application were not as marked as they were for phosphorus. This is mainly due to phosphorus being present in the effluent at twice the concentration of potassium (Table 6). There is also evidence that potassium ions are more mobile than phosphate and may have moved further down the profile (Smilde, 1980).

Lecomte (1980) found a significant increase in exhangeable potassium in the soil following applications of liquid cattle and pig slurry. Potassium undergoes a fixation process inside clay mineral lattices in clayey and loamy soils such as used in this trial and are thus removed from the soils stock of exchangeable potassium.

Kofoed and Nemming (1980) found with high rates of slurry application, supplying 1502 Kg K per hectare per annum for a 5 year period, that K was increased most in the surface layer and slightly down to 2 m.

TABLE 7 : SOIL ANALYSIS OF THE TREATMENT PLOTS BEFORE COMMENCEMENT AND AFTER COMPLETIONOF THE PROJECT

TREATMENT	DATE	water pH	COND.MS	P ppm	K ppm
Control 1	17.12.80	5.4	.20	130	321
	24.12.82	5.6	.40	149	415
Control 2	17.12.80	5.7	.19	161	381
	24.12.82	5.5	.20	138	275
Fresh 1	17.12.80	5.3	.25	155	241
	24.12.82	5.95	.45	660	421
Fresh 2	17.12.80	5.4	.27	147	269
	24.12.82	5.8	.50	828	423
Stored 1	17.12.80	5.25	.25	210	197
	24.12.82	5.8	.41	779	427
Stored 2	17.12.80	5.5	.20	140	319
	24.12.82	5.85	.39	710	329

Pasture Observations

The high rates of effluent application did not have adverse effects on pasture growth during the length of the trial except for some small localised areas of pasture burn. These were due to puddles forming for long periods during winter where the plots were not properly drained. During the summer months the pasture on the control plots dried off while pasture on the effluent plots continued to grow mainly due to the irrigation effect of the effluent. Growth was similar on all plots during winter.

Dulthion (1980) concluded that pig manure even with the very large amounts supplied in his trial did not inhibit the growth of grass. Pollock and O'Callaghan (1975) found that when they applied pig slurry at higher levels than desirable for maximum grass growth the grass yielded quite well despite the occurrence of some scorch.

The original method of grazing the plots was to alternate heavy grazing with rest periods. This method was used to allow measurement of pasture growth between grazing, however, it was abandoned after 6 months due to problems caused by preferential grazing. When a flock of sheep were introduced they tended to only graze the control plots. Three explanations are proposed for this :-

(1) Rejection of herbage contaminated by dung droppings is a well known feature of pastures and is influenced by stocking rate (Collins 1967). This type of rejection arises because animals have a choice between fresh and fouled grass (Collins 1980).

(2) The animals were very wary of the travelling irrigators for a 3 to 4 day period.

(3) The problem compounded itself when grass in the effluent plots became long and rank with the sheep preferring the short grass on the control plots.

As the primary consideration was to measure runoff which would be affected by groundcover it was decided to abandon pasture measurements in favor of permanently grazing the plots. With this method the sheep became accustomed to the irrigators and the effluent and grazed the grass in the whole trial area to an even height.

Changes in botanical composition of the pasture was not studied as the trial period of 2 years was considered too short to produce the changes of reduced clover and high grass percentage normally expected from high nitrogen levels

Runoff

Table 9 gives the volumes of effluent applied to plots and the runoff occurring from the plots.

In 1981 runoff did not commence on any plots until June. It then continued through until October on the control and stored plots and until November on the fresh treatment plots. In 1982 runoff was spread over a longer period but was much less intense than in 1981. In 1982 runoff commenced in March on the fresh plots and April on the stored and control plots. Runoff then continued to occur on all plots until the end of September.

The pasture was ready to accept the oxidation pond contents in December 1981 and in November and December 1982.

1981 was a much wetter year than 1982 particularly during the winter months when reduced evaporation is likely to lead to saturated soils and runoff. In the 7 months from April to September 441 mm of rain fell in 1981 and only 270 mm fell during the same period in 1982. This is reflected in much lower runoff during 1982 from the control plots. A summary of runoff is given in the following table.

Table 8 : Total Runoff Volumes (litres)

	Control	Fresh	Stored
1981	234,690	1,430,829	687,103
1982	38,364	593,738	275,482

Extra hydraulic loading by applying effluent to plots during periods of soil saturation resulted in large increases in runoff from these effluent treated plots. The reduced volume applied to the stored plots had decreased the runoff substantially from the volumes recorded on the fresh plots. Total runoff on the stored plots was 48% and 46% of the runoff on the fresh plots in 1981 and 1982 respectively.

From these results it appears there is a 5 to 6 month period at Cressy when any extra hydraulic loading in the form of effluent will result in an increase in runoff. The magnitude of the runoff caused by a given volume of effluent is dependent on the prevailing weather conditions.

TABLE 9 : TYPE AND VOLUME OF EFFLUENT APPLIED AND RUNOFF PER PLOT

The following table shows the volume of liquids applied to plots and leaving plots in runoff. Runoff in litres is given for the control, fresh and storred treatments. The fresh treatment recieved fresh effluent thriughout the year while the stored treatment recieved fresh effluent, sludge and oxidation pond liquid at different stages throughout the year.

	CONTROL	FRESH TREATMENT		STORED TREATMENT			
DATE	RUNOFF (litres)	FRESH EFFLUENT (litres)	RUNOFF (litres)	FRESH EFFLUENT (litres)	SLUDGE (litres)	OXIDATION POND (litres)	RUNOFF (litres)
1981							
January		188,800		208,000			
February		145,600		179,200			
March		170,400		155,200			
April		178,400		154,400			
May		206,400		196,800			
June	4,083	232,000	149,278		69,600		27,690
July	65,498	228,800	482,445		75,200		218,680
August	122,508	248,000	607,938		68,800		328,908
September	18,283	188,800	75,970		65,600		26,980
October	24,318	168,800	110,050	176,000			84,845
November		161,600	5,148	145,600			
December		168,000		215,200		235,200	
1982							
January		235,200		246,400			
February		228,800		256,800			
March		284,000	9,407	240,000			
April	1,953	247,200	15,975	224,000			29,820
May	888	252,800	73,485	264,800			69,758
June	888	258,400	151,585		69,800		35,500
July	24,140	260,000	124,428		69,600		45,618
August	200	198,400	65,675		68,000		15,798
September	10,295	132,800	153,183		64,000		78,988
October		144,800		150,400			
November		198,400		205,600		130,400	
December		186,000		193,600		81,200	

Table 11 gives the total amounts of waste constituents applied to the pasture or leaving the pasture in the surface runoff water for each treatment. This table is a summary of information contained in Appendix 1.

The larger volumes of runoff in 1981 resulted in much greater losses of BOD, N, P, K in both effluent treatments and also the control plots.

Losses in runoff from the stored plots were less than half those of the fresh plots though substantially greater than the control plots.

The ability of the pasture to filter effluent constituents under the two regimes can be gauged by determining the percentage of an applied constituent that is lost in runoff.

Table 10 : Percentage of Applied Constituents in Runoff

		BOD_5	Nitrogen	Phosphorus	Potassium
Fresh	1981	3.8	16.4	8.8	5.8
	1982	2.2	7.0	0.8	2.1
Stored	1981	2.1	4.3	1.1	1.9
	1982	0.5	4.1	0.4	0.7

Percentage loss was higher for all constituents in the fresh treatment in both years and higher within each treatment in 1981 the wetter year. Phosphorus and potassium are filtered more strongly than nitrogen. BOD is also efficiently removed from the effluent.

If the phosphorus and potassium in effluent can make contact with the soil they can form insoluble complexes that are resistant to loss in surface runoff water unless soil erosion occurs. However applying effluent when the soil was saturated led to direct runoff of the effluent with surface water. Filtering and dilution occurred to some extent during these times, however, the detention time in the soil pasture matrix was not sufficient to prevent considerable pollution of the surface water leaving the plots.

TABLE 11 : TOTAL ANNUAL AMOUNTS PER HECTARE OF BOD_5, N,P,K APPLIED IN SUMMARY AND COLLECTED IN RUNOFF

TREATMENT	TYPE	DATE	BOD_5	NITROGEN	PHOSPHORUS	POTASSIUM
CONTROL	RUNOFF	1981	34.7	3.0	0.4	0.8
		1982	4.87	0.8	0.2	0.3
FRESH	APPLIED	1981	20986.2	3976.0	924.9	509.6
		1982	22339.1	4471.3	1591.1	706.2
	RUNOFF	1981	801.3	653.8	81.1	29.6
		1982	482.9	313.0	13.0	14.7
STORED	APPLIED	1981	16310.4	3217.6	848.4	474.9
		1982	21834.4	3527.1	1350.0	644.2
	RUNOFF	1981	348.0	137.3	9.6	8.9
		1982	112.0	143.3	5.5	4.5

The runoff water quality for each plot and for each month that runoff occurred is presented in Appendix 2.

Within treatments there was no marked tendency for constituent concentrations to be higher in either year. The difference in total nutrients in runoff between the two years was therefore due to higher volumes of runoff in 1981 rather than higher concentrations in the runoff.

The monthly analysis of runoff water over the two year period can be averaged for each treatment to highlight treatment differences. The average constituent levels over the whole trial is included for comparison.

Table 12 : Average of Monthly Runoff and Effluent Constituents

	BOD_5	pH	Settleable Solids (mg/L)	Total Solids (mg/L)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	Ntotal (ppm)
Control	60	7.5	1.0	599	1.8	2.5	N.D	12.6
Fresh	316	7.9	3.8	1067	8.5	9.9	N.D	208.6
Stored	230	7.9	3.5	748	7.8	7.3	N.D	107.0
Effluent	3882	7.8	50.4	4874	233.9	113.3	.8	770.5

Levels of constituents in the runoff from the stored plots were lower than the fresh plots. The higher total amounts of constituents leaving the fresh plots were therefore due to a combination of higher concentrations and higher volumes of runoff.

BOD, P and K appeared to be strongly filtered by the soil pasture matrix whereas total nitrogen appeared to be weakly held and susceptible to losses in runoff. Total solids values were high for the control plot indicating that most of the solids added by the effluent in both treatments were filtered out. No nitrate nitrogen was found in the runoff waters. When nitrate is formed it may leach into the soil and also low winter temperatures reduce the nitrification rate.

Samples of surface runoff were taken as soon as the runoff water left the effluent treated plots. There is evidence that substantial reduction in pollution load can be achieved by passing the surface water over a buffer strip that does not receive effluent directly. Dodge et al (1975) investigated forest buffer zones in improving the quality of manure polluted runoff from applications of cattle slurry to pasture. They achieved the following results:-

Table 13 : Buffer Strips

Distance from slurry application (metres)	N ppm	P ppm	K ppm
0	97.2	33.9	366.67
3.8	5.2	0.08	19.3

They concluded that components of the manure reached the 3.8 m distance in sufficient quantity to represent a pollution hazard and that a forest buffer strip of 7.6 m is sufficient to prevent stream pollution from animal wastes.

Drainage Water

Drains were laid at a depth of 30 cm under all plots. Drain flow only occurred during August and September in 1981 and July and September ln 1982. Appendix 3 contains the analysis of drain water collected during during these months.

The following table summarises the level of constituents found in the drainwater.

Table 14 : Average Constituent Levels in Drainwater

	BOD_5	pH	Settleable Solids (mg/L)	Total Solids (mg/L)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	Ntotal (ppm)
Control	40	6.8	0.7	545	0.2	0.6	3.5	7.8
Fresh	64	6.8	1.3	1590	0.7	3.8	54.5	60.8
Stored	90	7.4	1.4	896	1.0	1.5	15.3	21.1

Application of effluent did not cause large increases in BOD, settleable solids, or total solids levels over those found for the control plots. Much of the BOD and solids in effluent is contained in the organic matter which is effectively filtered by the soil and grass.

Phosphorus concentrations in the drainage water were low for both treatments and the control. Soils with a high clay content such as those used in this trial have a very high adsorptive capacity for phosphorus. Phosphorus applied to soils is converted to water insoluble forms in a short time and many authors have found phosphate leaching after effluent application to be insignificant (Dulthion *et al* 1980; Lecomte 1980; Finck 1982).

Koelliker and Miner (1969) reported that water from tile drains at a depth of 122 cm contained 0.5 ppm phosphorus during a season in which the soil was irrigated with livestock waste water containing 552 kg of phosphorus per hectare.

Like phosphorus the potassium in effluent can undergo fairly intense fixation with the clay in the soil. However more potassium reached the 30 cm depth than phosphorus indicating the fixation process is less intense for potassium in this soil. Smilde (1980) found that following three annual applications of large amounts of cattle slurry soluble P had penetrated to 40 cm and exchangeable K to 80 cm.

Most of the nitrogen found in the drainage water was in the nitrate form. Nitrate is a negatively charged ion and moves freely in the soil water making it susceptible to leaching. Ammonium ions on the other hand are positively charged and are attracted to negatively charged clay and organic colloids.

The results of research into nitrogen leaching following animal waste applications vary widely. The complicated factors that control nitrification and dentrification in the soil play a large part in the variability of these results.

Randall et al (1975) applied very high rates of cattle manure to soil, 22,590 kg N/ha. They found that the nitrate concentrations in the soil solutions at 180 cm to be consistently higher in the control follow than in the manured areas due to dentrification.

Dulthion et al (1980) applied high rates of effluent, supplying 4,116 Kg N/ha for a 3 year period to 3 soil types. Leaching did not exceed 6 to 9 percent of the total nitrogen supplied. The average nitrate concentration in drainage waters leaving these plots was 53 ppm which is very similar to the average nitrate level found in the fresh plot drainage water in this trial.

Vetter (1980) states that the nitrogen concentration in the groundwaters of heavy soils are similar, or sometimes a little higher, than in sandy soils, but the amount of nitrogen leached from heavier soils is generally less than for sandy soils, because there is less drainage water.

Kofoed and Nemming (1980) after applying 1,814 kg N/ha for 6 years to a loamy soil found the content of nitrate nitrogen to be 12 ppm at 50cm falling to 40 ppm at 200cm.

Marriot and Barlett (1975) injected dairy manure beneath the surface of orchardgrass at an annual rate of application of 3920 kg N/ha. The average annual concentration of nitrate nitrogen at 30 cm was 11 ppm nitrate.

Water Balance Model (WBAL3)

Pollution from effluent application occurs through runoff into streams and watercourses and through leaching into groundwaters. Both these events occur when the ground is saturated. To maximize the effluent load that pasture can treat without causing pollution the retention time of the effluent in the soil pasture matrix must be at a maximum.

Whether runoff will be caused by a given application of effluent is dependent on a number of factors including soil moisture deficit, volume of effluent applied, crop or pasture characteristics, soil characteristics, rainfall evaporation, transpiration and slope. Therefore the volume of effluent that can be applied to pasture varies widely from location to location.

The flexibility required for efficient management of effluent to minimize pollution may dictate that storage is required at certain times of the year. A soil water balance model may be used as a management tool for estimating storage requirements and application times and volumes that can be applied without increasing natural runoff.

Pollock and O'Callaghan (1975) tested a system where soil moisture deficit was calculated from actual weekly rainfall figures collected on site in conjunction with average evapotranspiration figures for the area. This then allowed slurry applications to make up the estimated deficit, however, rates had to be reduced because of the danger of sward kill. They found the system reasonably accurate and useful as an effluent management aid. The total efficiency of purification of slurry amounted to approximately 98 percent.

A water balance model WBAL3 (Rosenthal et al, 1976) was tested by comparing predicted runoff volumes for each plot with runoff volumes actually measured. The water balance accounting procedure used in this model is based on the Fitzpatrick and Nix (1969) model.

The general water balance equation is :-

Rainfall = runoff + change in surface detention

+ change in soil water storage + evaporation

Water balance accounting is carried out on a weekly basis with rainfall and free water evaporation as input parameters. Flexibility was achieved by requiring that the user specify all parameters in the model such as:

- initial soil water storage,
- maximum possible water storage in the soil,
- minimum daily infiltration rate at full storage and maximum daily infiltration rate at zero storage,

- the crop function which relates the potential for evapotranspiration to the stage of crop development,
- the relative available water function which relates the ratio of actual to potential evaporation, to the available water storage.
- crop surface detention curve to be used (Rosenthal *et al*, 1976).

Appendices 4 and 5 give the hydrological data for the years 1981 and 1982 respectively. The weekly rainfall and evaporation figures were recorded at the Cressy meteorological station.

The evaporation and transpiration losses of water from a soil pasture system are considered together as evapotranspiration. The potential evapotranspiration is the loss rate when water is freely available to a crop. At any level of potential evapotranspiration, the ability of the plant to remove water from the soil depends on a number of soil, plant and atmospheric parameters, the most important of which is the amount of soil water available for plant use (Rosenthal *et al*, 1976).

The calculated soil water storage at the end of each week is also included for each plot.

The actual runoff measured for each plot was converted to mm for comparison with the predicted runoff values produced by the WBAL3 model. The concepts and functions used in this model for predicting runoff are adapted from those used by Boughton (1968).

Surface detention and infiltration are important factors affecting runoff. A portion of the rainfall is considered to be detained in minor depressions on the soil surface or on any above ground vegetative material. This water is not available for surface runoff and so is excluded from its calculation. The portion of the effective rainfall which enters the soil is a function of the infiltration characteristics of the soil and the amount and duration of rainfall (Rosenthal et al, 1976).

For the runoff estimations from the fresh and stored plots the effluent applied was added to the rainfall and then input into the model.

Figures 3 and 4 graph the calculated soil water storage for each treatment for 1981 and 1982 respectively. Little difference was evident between the two years for any treatment. In 1981 soil water levels reached saturation later in the year than in 1982. However in 1981 the period of high soil water storage persisted to later in the year than 1982.

A trough in soil water storage occurred early in the year for all treatments in both years. This indicates that a far greater volume of effluent could be applied in the January, February, March period than was applied in this project before reaching soil storage levels that are likely to result in runoff.

The period of saturation or near saturation was much shorter for the control than the two effluent treatments in both years, however, there was no marked difference between either effluent treatment in 1981 or 1982. The stored treatment, however, did have higher storage levels late in each year due to extra applications from the oxidation pond although these levels did not reach saturation. The extra hydraulic loading in December 1981 resulted in higher storage levels in the stored treatment plots during the early part of 1982.

Figures 5 and 6 depict the rainfall and predicted and actual runoff values for 1981 and 1982 respectively.

The model accurately predicted those weeks in which runoff would occur. In 1981 runoff predicted tended to be higher than actually occurred. In 1982 both the predicted and actual runoff were very low with runoff only being registered in three weeks of the year.

High rainfall during the period from week 25 to week 40 in 1981 led to runoff being predicted to occur in 12 weeks during this period and actually occurring in 11 weeks.

The rainfall pattern in 1982 was more evenly distributed throughout the year with a lower total annual rainfall, 604 mm in 1981 and 453 mm in 1982. The lower rainfall during the critical winter months resulted in less runoff during 1982. The high rainfall during week 49 of 1982 did not result in runoff due to the high soil moisture deficit at that time.

Figures 7 and 8 depict the rainfall plus effluent applied to the fresh treatment plots and the predicted and actual runoff occurring during 1981 and 1982 respectively.

Both predicted and actual runoff were much higher in 1981 than 1982. The water balance model accurately predicted when runoff events would occur in both years for this treatment. The length of the period of consistent runoff was similar for both years, from week 22 to 42 in 1981 and from week 17 to 38 in 1982.

The model also satisfactorily predicted the volumes of runoff that would occur. In 1981 the model tended to overestimate the amount of runoff that would occur predicting 367 mm whereas 316 mm of runoff actually occurred. The predicted and actual values were very close in 1982, 129 mm was the average predicted and 137 was the average actual runoff per year.

Figures 9 and 10 depict the rainfall plus effluent applied to the stored treatment plots and the predicted and actual runoff occurring during 1981 and 1982 respectively.

Runoff was much lower from the stored plots than the fresh plots in both years. Runoff from the stored plots was 44% and 41% of of the runoff from the Fresh plots in 1981 and 1982 respectively. In both years this was due to a reduction in volume per week rather than a reduction in the number of weeks during which runoff occurred.

As with the control and stored treatment runoff was much higher in 1981 than 1982 due to the higher rainfall.

Again for the stored treatment the model was very good at predicting when runoff events would occur. Runoff started to occur earlier in the year in 1982. This was due to both the rainfall distribution and the higher soil water storage levels at the start of 1982 caused by the application of the oxidation pond liquid at the end of 1981.

The model satisfactorily estimated volumes of runoff, however, in both years it tended to overestimate runoff. In 1981 the predicted runoff was 182 mm while the actual runoff was 142 mm, in 1982 the predicted runoff was 79 mm and the actual was 57 mm.

An option can be set in the model to keep soil water storage above specified levels by means of irrigation. The average rainfall and evaporation figures for Cressy for the period from 1939 to 1982 were fed into the program at the soil water storage was kept at 80 mm with irrigation when required. The water balance model predicted that effluent could be applied at the rate of 119 mm in Summer, 57 mm in Autumn, 0 mm in Winter and 67 mm in Spring without causing a significant increase in runoff. For the heavily diluted effluent produced at Cressy this equates to an effluent loading of 20 sows and progeny per hectare under an optimum application strategy.

CALCULATED SOIL
WATER STORAGE

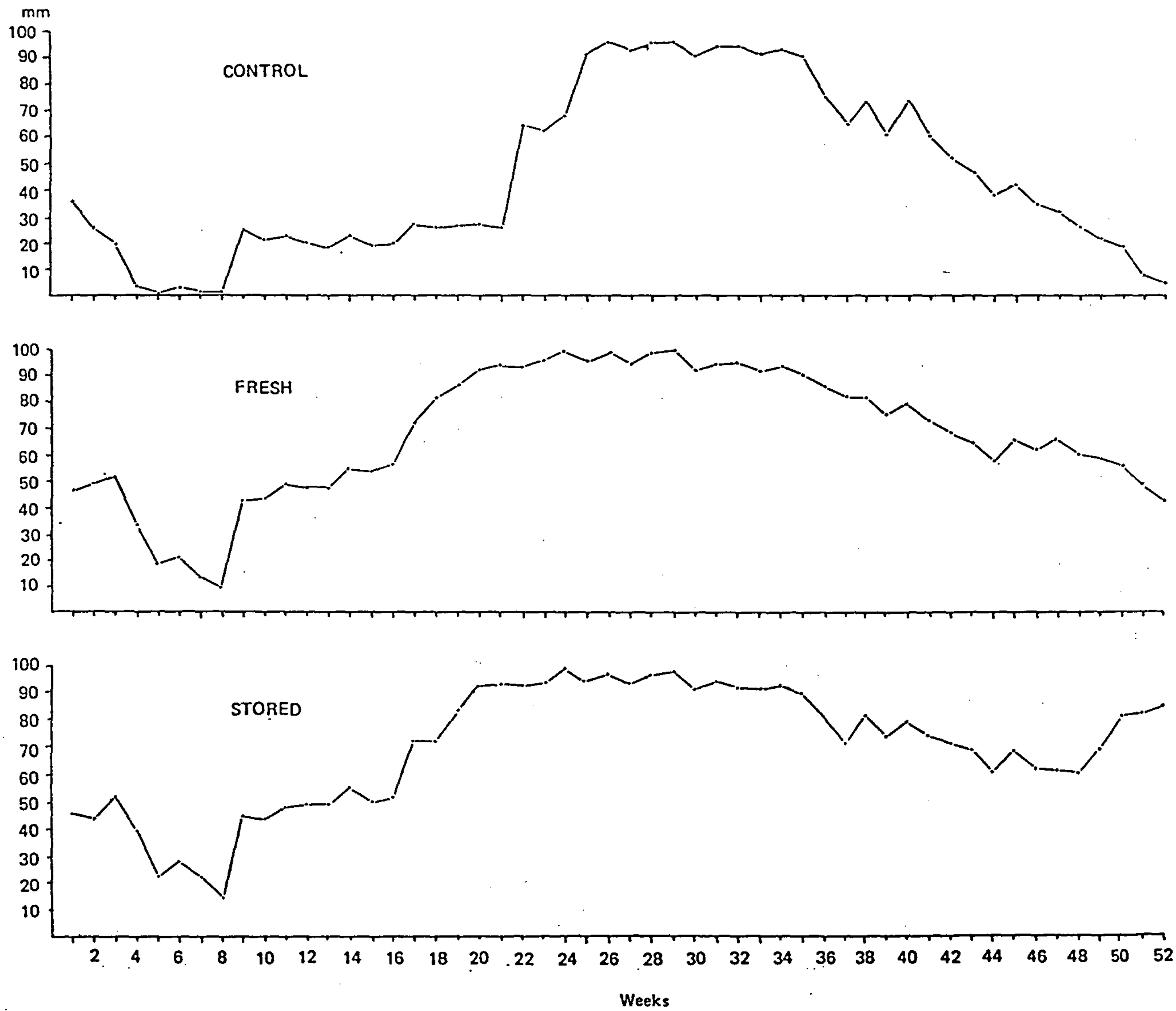

FIGURE 3 : SOIL WATER STORAGE 1981

CALCULATED SOIL
WATER STORAGE

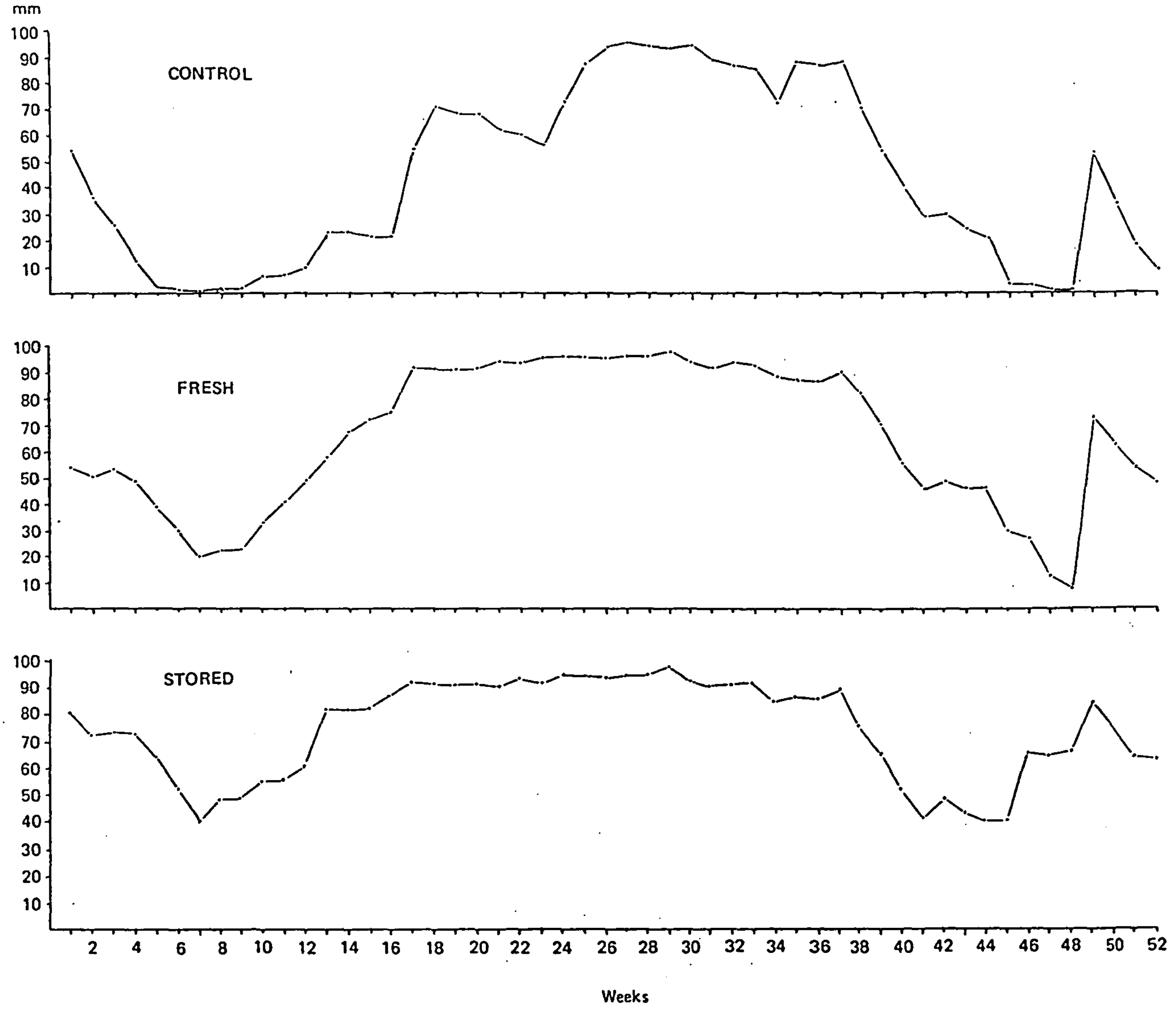

FIGURE 4 : SOIL WATER STORAGE 1982

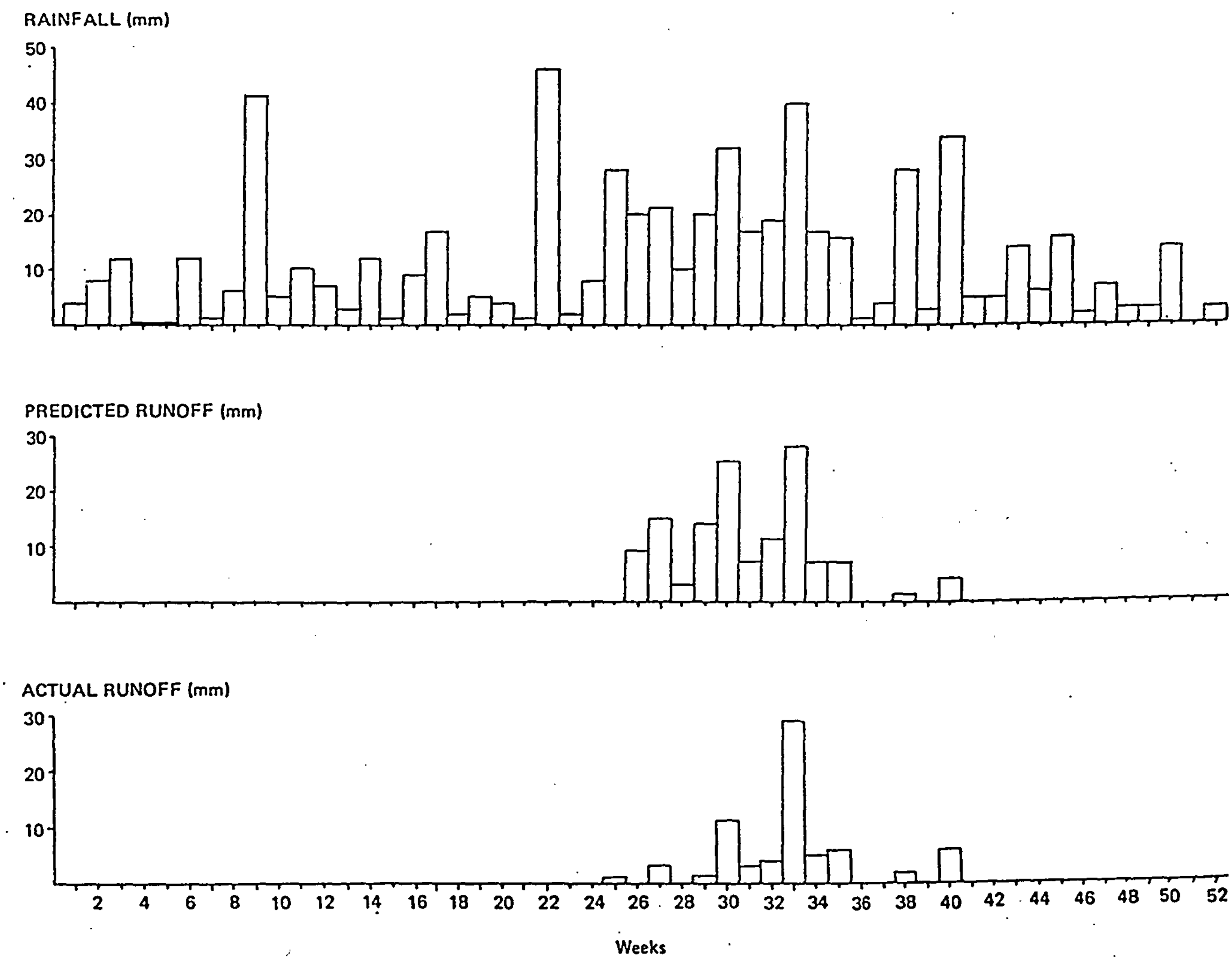

FIGURE 5 : CONTROL HYDROLOGICAL DATA 1981

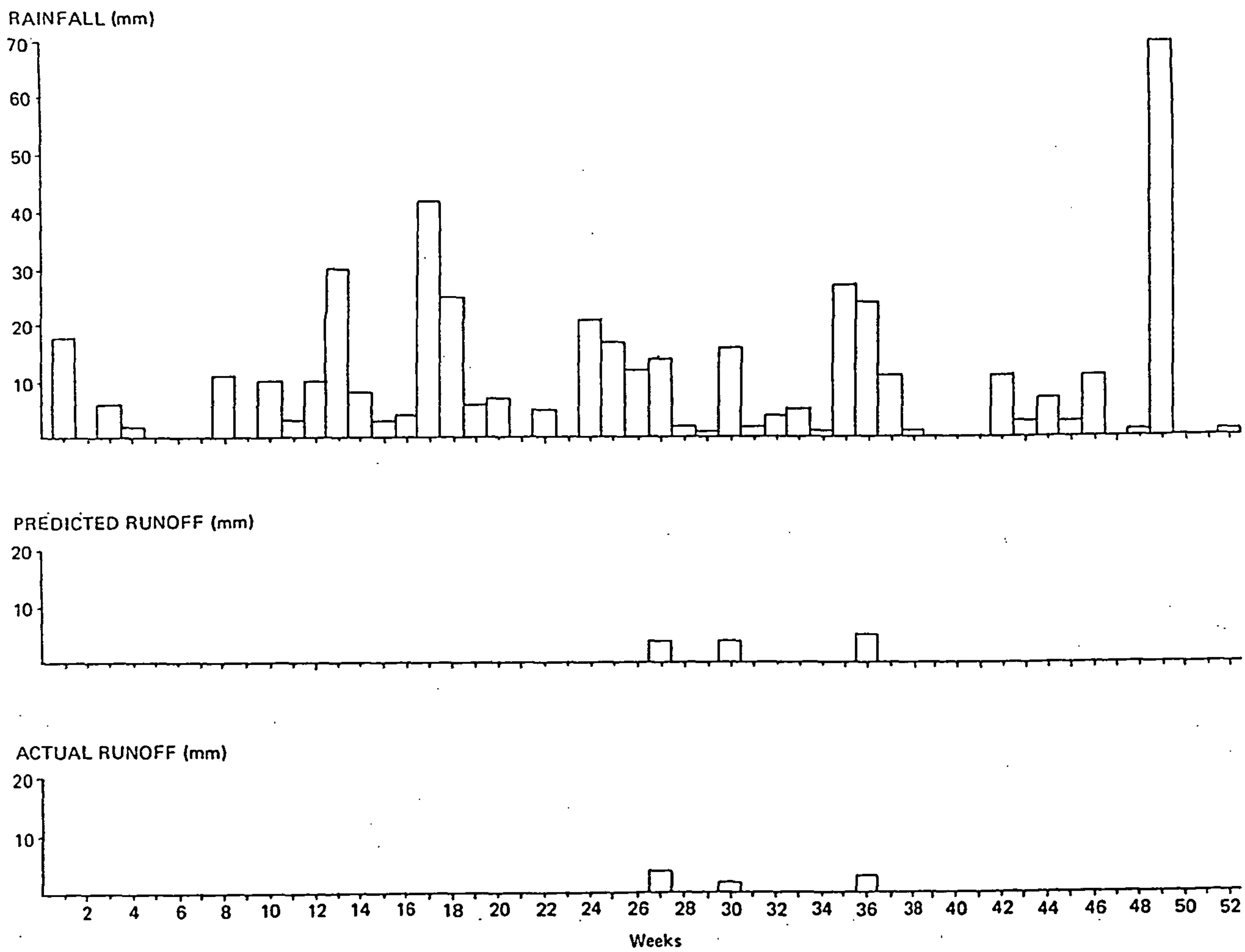

FIGURE 6 : CONTROL HYDROLOGICAL DATA 1982

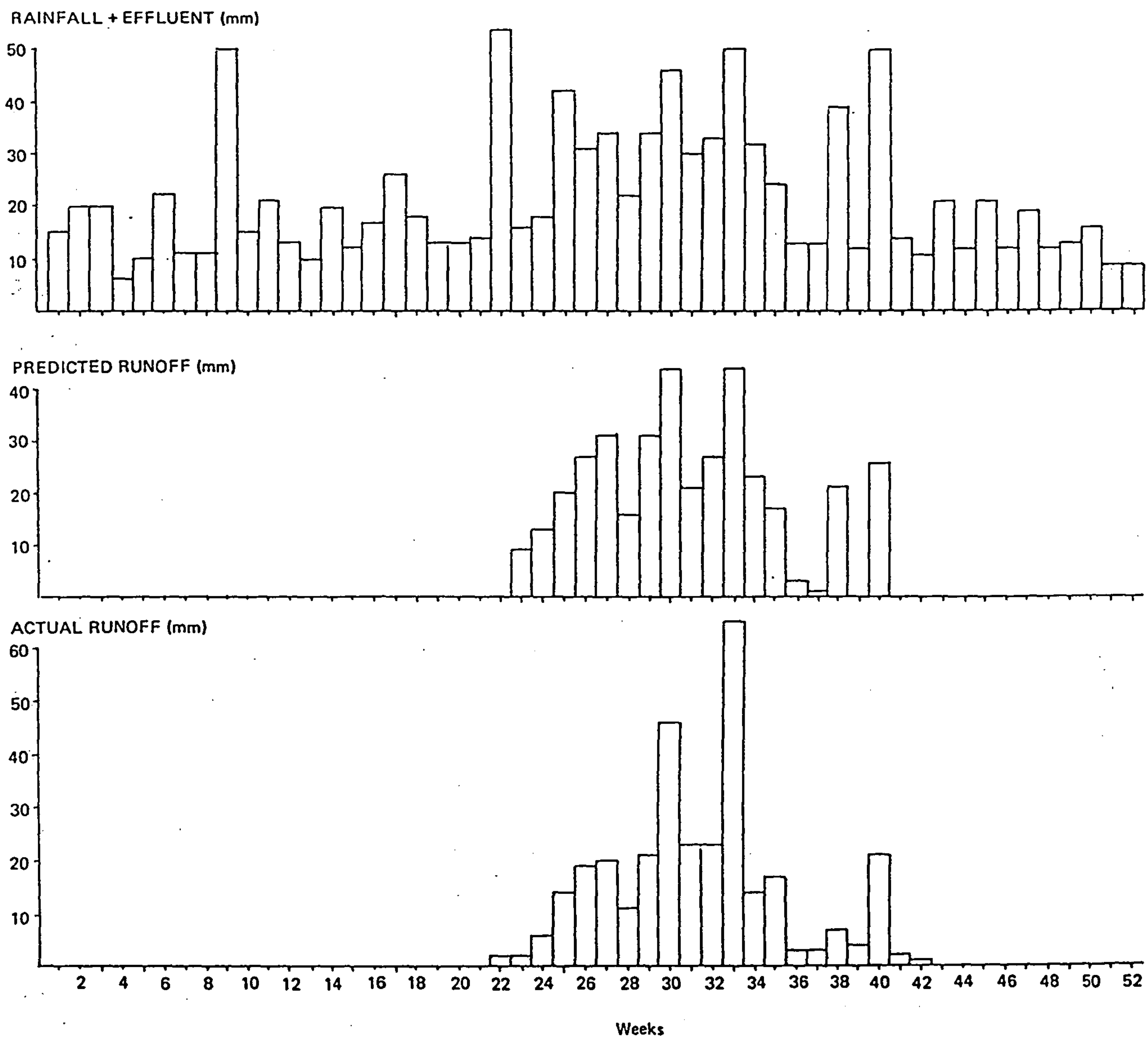

FIGURE 7 : FRESH TREATMENT HYDROLOGICAL DATA 1981

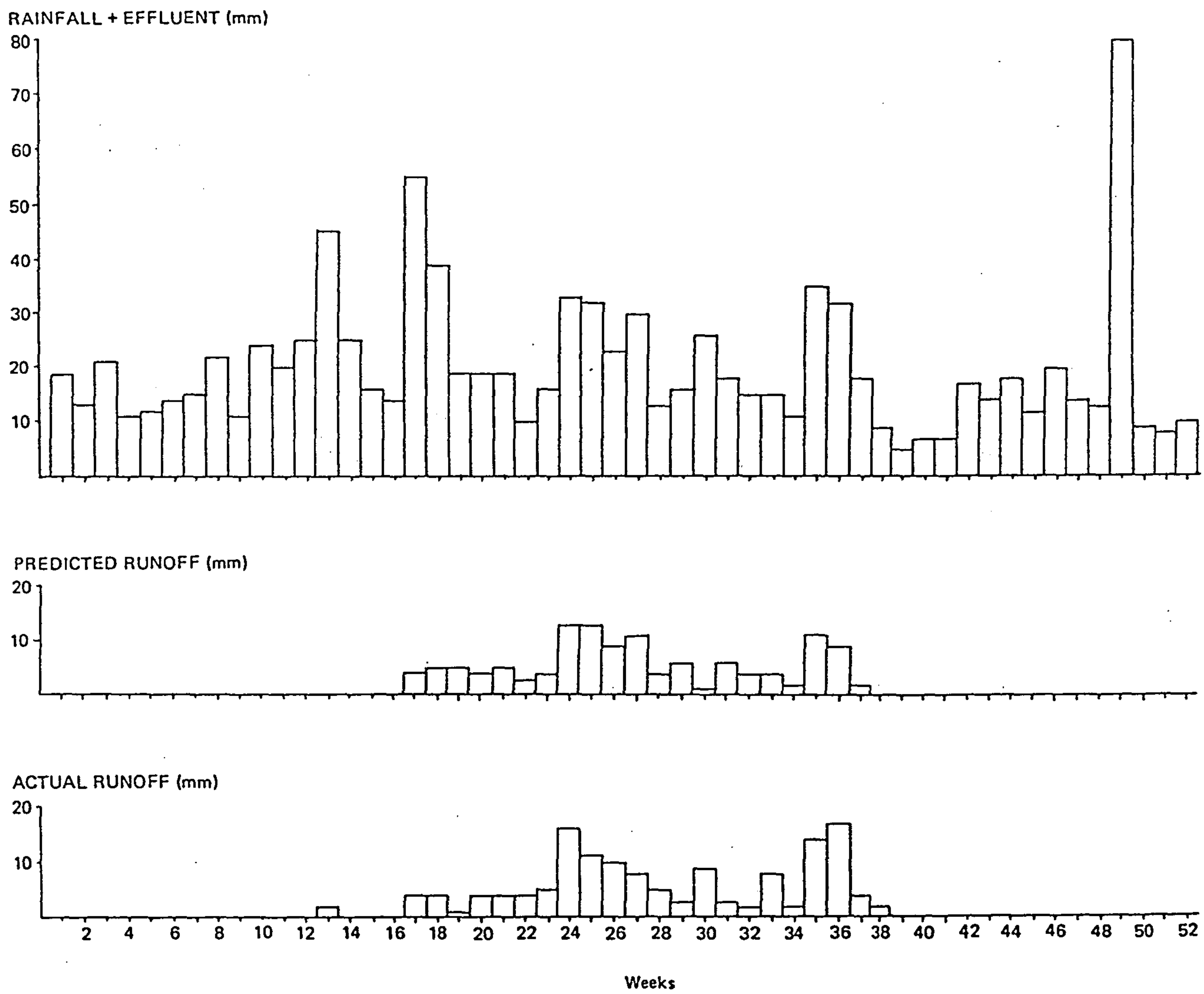

FIGURE 8 : FRESH TREATMENT HYDROLOGICAL DATA 1982

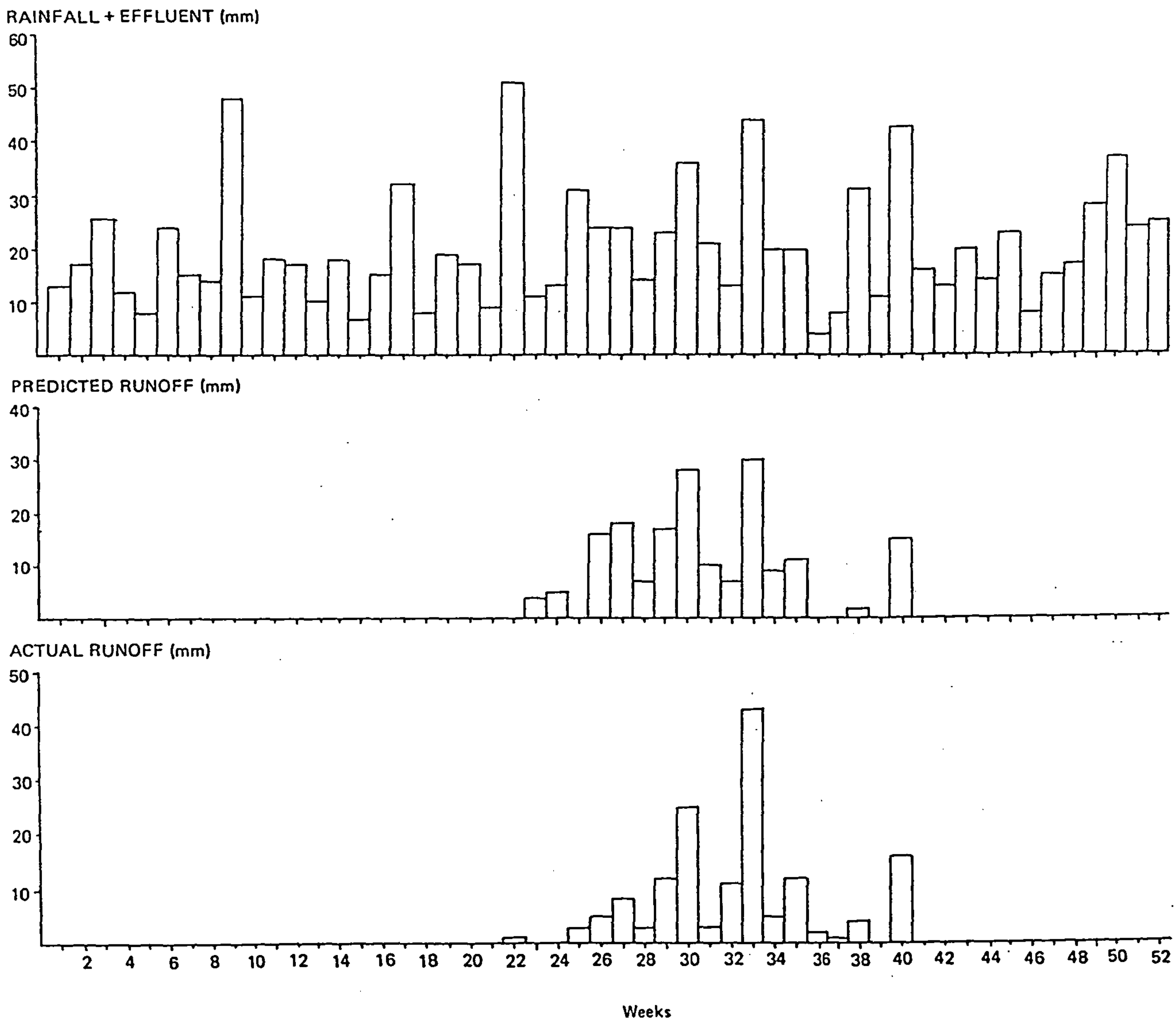

FIGURE 9 : STORED TREATMENT HYDROLOGICAL DATA 1981

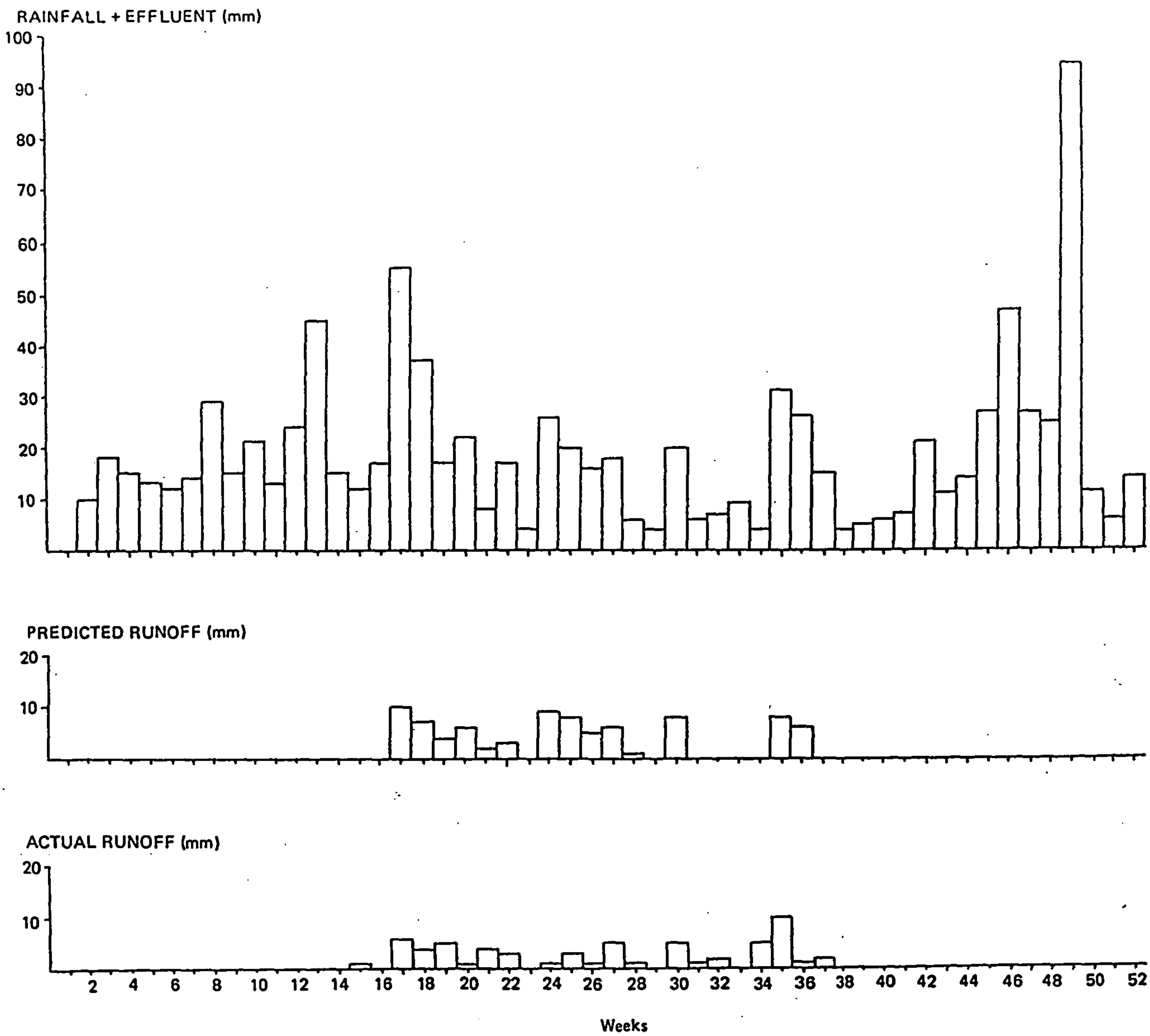

FIGURE 10 : STORED TREATMENT HYDROLOGICAL DATA 1982

5. CONCLUSION

Intensification of the pig industry has meant that large numbers of animals can be housed on small areas of land with feed being imported on to the farm. If the land available for effluent application is small relative to the number of animals housed then the major aim of effluent management is disposal rather than utilization.

Pasture and soil can be thought of as an aerobic treatment system. Like the more expensive and sophisticated systems used for purification of municipal sewage for disposal to water, land disposal of animal wastes requires careful management to achieve maximum efficiency.

The aim of high rate land disposal is to assimilate the applied effluent constituents without damaging the environment. Reduction in the potential of effluent applied to pasture to pollute occurs through the interaction of chemical and biological processes. These include reduction of BOD through oxidation and breakdown of the carbonaceous and nitrogenous products in the waste, losses of waste nutrients to the atmosphere such as CO_2 and gaseous nitrogen losses through ammonification and denitrification, adsorption of nutrients such as phosphorus and potassium in the soil and conversion of nutrients into plant material.

The extent to which these beneficial processes occur is dependent on the retention time in the system. Breakdown of waste by soil microbes and the subsequent chemical reactions with the soil must be given sufficient time to occur. The principle factor determining retention time is soil moisture level. If effluent is applied to a saturated soil then the pollutants may leave the system through leaching into groundwaters or in surface water runoff before the soil pasture system has had time to render the applied pollutants innocuous.

Therefore efficient management of high rate disposal is dependent on applying effluent when the soils potential for hydraulic loading is high and thus the retention time should not be short. This flexibility can only be gained through storage during unsuitable times of the year.

The effect of soil moisture loss is shown clearly in this trial in the difference between years and between treatments. 1982 was a drier year than 1981 particularly during the critical winter months. From Table 13 it can be seen that total nutrient loss in 1982 was approximately 50% of the 1981 loss for both treatments even though a similar nutrient load was applied. The effect of the combined hydraulic loading of rainfall plus effluent is also shown in the difference between the two treatments. The stored treatment was a compromise between applying a reduced hydraulic loading during the winter months and also reducing the storage required by applying the high BOD sludge to pasture. The total runoff on the stored plots was 48% and 46% of the runoff on the fresh plots in 1981 and 1982 respectively.

Even though the stored treatment markedly reduced the volume of runoff the concentration of pollutants in the runoff was still too high for direct discharge into watercourses. This was caused by the applied effluent being washed off the pasture before it had time to be assimilated. Three possible approaches to abating this problem are:

(1) Do not apply any effluent during periods of runoff.

(2) Collect and store runoff from the treatment area to be reapplied when suitable conditions prevail.

(3) Incorporate a large enough buffer strip between the treatment area and any watercourse to provide sufficient filtration to achieve acceptable concentrations

The settling tank and oxidation pond used in this project proved to be a simple and functional system. Oxidation ponds are much less prone to odour nuisance than anaerobic systems. Separation or pretreatment is required however for high BOD wastes such as animal wastes otherwise the land area required for effective operation of oxidation ponds would be prohibitive.

Careful management of high rate effluent application can increase the level of environmentally acceptable losses. Regular spreading of smaller amounts of effluent is more easily coped with by pasture than the same amount of effluent applied in large widely spread doses. Thin spreading on the surface also result in greater losses due to ammonia volatilization from more rapid drying. Wetting and drying creates alternate aerobic and anaerobic conditions which encourage nitrogen losses through ammonia volatilization and denitrification. Intermittent irrigation of the treatment area with water during the summer months may be a management strategy that would result in considerable environmentally acceptable nitrogen loss.

In the short term nitrogen pollution is the major source of environmental concern however in the longer term build up of nutrients such as potassium and phosphorus may cause problems through toxicity or interactions with other nutrients. The effect of this build up would depend on soil characteristics such as clay content and would require continuing soil and pasture monitoring.

Because of the large variations between areas in climate and soil characteristics it is impossible to give blanket recommendations for effluent disposal rates. A water balance model such as WBAL3 (Rosenthal et al, 1976) can be used as a valuable aid for effluent management in any given region.

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APPENDIX 1 : EFFLUENT CONSTITUENTS APPLIED AND IN RUNOFF

BIOCHEMICAL OXYGEN DEMAND

DATE	TREATMENT	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	CONTROL	RUNOFF	0.0	0.0	0.0	0.0	0.0	0.4	3.8	9.8	0.5	1.0	0.0	0.0
	FRESH	APPLIED	477.7	368.4	431.1	419.2	485.0	545.2	1457.5	1579.8	1202.7	839.0	803.2	835.0
		RUNOFF	0.0	0.0	0.0	0.0	0.0	45.5	166.4	82.7	26.7	39.3	0.0	0.0
	STORED	APPLIED	526.2	453.4	392.7	362.8	462.5	613.8	663.3	606.8	578.6	874.7	723.6	1081.3
		RUNOFF	0.0	0.0	0.0	0.0	0.0	9.0	56.0	59.2	9.4	23.0	0.0	0.0
1982	CONTROL	RUNOFF	0.0	0.0	0.0	0.12	0.05	0.12	1.35	0.01	0.52	0.0	0.0	0.0
	FRESH	APPLIED	1011.4	983.8	1221.2	882.5	902.5	922.5	1021.8	880.0	621.9	439.2	601.7	564.1
		RUNOFF	0.0	0.0	3.2	5.5	25.4	100.8	16.8	11.2	54.4	0.0	0.0	0.0
	STORED	APPLIED	1059.5	1104.2	1032.0	799.7	945.3	901.1	898.5	777.9	626.3	456.2	632.2	592.6
		RUNOFF	0.0	0.0	0.0	5.6	13.1	8.2	5.6	3.1	14.8	0.0	0.0	0.0

APPENDIX 1 : EFFLUENT CONSTITUENTS APPLIED AND IN RUNOFF (CONT'D)

TOTAL NITROGEN

DATE	TREATMENT	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	CONTROL	RUNOFF	0.0	0.0	0.0	0.0	0.0	0.12	0.46	0.37	0.17	0.22	0.0	0.0
	FRESH	APPLIED	145.0	111.8	130.9	127.4	147.4	165.7	179.6	194.7	148.2	148.5	142.2	147.8
		RUNOFF	0.0	0.0	0.0	0.0	0.0	26.6	144.7	93.0	9.8	20.1	0.0	0.0
	STORED	APPLIED	159.7	137.6	119.2	110.2	140.5	67.6	73.0	66.8	63.7	154.9	128.1	226.6
		RUNOFF	0.0	0.0	0.0	0.0	0.0	4.4	42.6	5.6	2.7	6.5	0.0	0.0
1982	CONTROL	RUNOFF	0.0	0.0	0.0	0.02	0.009	0.04	0.2	0.002	0.08	0.0	0.0	0.0
	FRESH	APPLIED	199.2	193.8	240.5	182.9	187.1	191.2	254.3	194.0	129.9	65.4	89.7	84.1
		RUNOFF	0.0	0.0	2.2	3.7	17.1	48.7	21.4	12.5	35.4	0.0	0.0	0.0
	STORED	APPLIED	208.7	217.5	203.3	165.8	196.0	80.5	80.3	78.5	73.9	68.0	114.0	100.7
		RUNOFF	0.0	0.0	0.0	3.2	7.4	4.0	3.9	2.6	43.4	0.0	0.0	0.0

APPENDIX 1 : EFFLUENT CONSTITUENTS APPLIED AND IN RUNOFF (CONT'D)

PHOSPHORUS

DATE	TREATMENT	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	CONTROL	RUNOFF	0.0	0.0	0.0	0.0	0.0	0.01	0.10	0.06	0.003	0.02	0.0	0.0
	FRESH	APPLIED	24.7	19.1	22.3	23.4	29.5	33.2	46.9	50.8	38.7	43.2	41.4	43.0
		RUNOFF	0.0	0.0	0.0	0.0	0.0	9.1	9.0	7.5	4.9	6.0	0.0	0.0
	STORED	APPLIED	27.3	23.5	20.3	22.1	28.1	21.6	23.3	21.3	20.3	45.1	37.3	56.3
		RUNOFF	0.0	0.0	0.0	0.0	0.0	0.4	1.8	1.3	0.2	0.6	0.0	0.0
1982	CONTROL	RUNOFF	0.0	0.0	0.0	0.01	0.006	0.002	0.04	0.0001	0.01	0.0	0.0	0.0
	FRESH	APPLIED	56.5	54.9	68.2	43.5	44.5	45.5	94.1	71.8	48.1	51.8	71.0	66.6
		RUNOFF	0.0	0.0	0.09	0.15	0.7	2.3	1.0	0.5	1.1	0.0	0.0	0.0
	STORED	APPLIED	59.1	61.6	57.6	39.4	46.6	27.7	27.6	26.9	25.3	53.8	74.2	69.7
		RUNOFF	0.0	0.0	0.0	0.27	0.64	0.34	0.47	0.13	0.62	0.0	0.0	0.0

APPENDIX 1 : EFFLUENT CONSTITUENTS APPLIED AND IN RUNOFF (CONT'D)

POTASSIUM

DATE	TREATMENT	TYPE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1981	CONTROL	RUNOFF	0.0	0.0	0.0	0.0	0.0	0.02	0.18	0.10	0.01	0.05	0.0	0.0
	FRESH	APPLIED	21.9	16.9	19.8	14.8	17.1	19.3	22.4	24.3	18.5	18.4	17.6	18.3
		RUNOFF	0.0	0.0	0.0	0.0	0.0	1.3	6.3	4.3	0.5	0.9	0.0	0.0
	STORED	APPLIED	24.1	20.8	18.0	12.8	16.3	9.9	10.7	9.8	9.3	19.2	15.9	25.8
		RUNOFF	0.0	0.0	0.0	0.0	0.0	0.3	2.6	0.5	0.1	0.5	0.0	0.0
1982	CONTROL	RUNOFF	0.0	0.0	0.0	0.006	0.003	0.003	0.1	0.001	0.02	0.0	0.0	0.0
	FRESH	APPLIED	24.9	24.3	30.1	21.8	22.3	22.7	40.1	30.6	20.5	22.0	30.2	28.3
		RUNOFF	0.0	0.0	0.1	0.18	0.82	2.25	0.95	0.73	1.57	0.0	0.0	0.0
	STORED	APPLIED	26.1	27.2	25.4	19.7	23.3	14.2	14.1	13.7	12.9	22.9	32.6	37.7
		RUNOFF	0.0	0.0	0.0	0.23	0.54	0.29	0.31	0.15	0.50	0.0	0.0	0.0

APPENDIX 2 : RUNOFF WATER QUALITY

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
CONTROL PLOT 1	JUNE 1981	3	50	7.5	0.5	260	2.8	4.2	N.D	8
	JULY 1981	10	55	7.5	0.6	800	1.3	2.8	N.D	7
	AUG 1981	10	68	7.3	1.7	1470	0.27	1.2	N.D	4
	SEPT 1981	5	52	8.0	0.3	1320	0.72	0.81	N.D	13
	OCT 1981	3	50	7.5	0.2	790	0.97	1.75	N.D	12
	MAY 1982	2	47	7.4	0.3	400	1.38	2.85	N.D	10
	JUNE 1982	5	72	8.0	1.0	910	2.2	3.9	N.D	10
	JULY 1982	5	62	7.5	0.01	800	2.43	4.68	N.D	5
	AUG 1982	3	28	7.5	0.6	200	0.33	0.99	N.D	11
	SEPT 1982	6	47	7.1	0.1	250	1.39	2.68	N.D	11

APPENDIX 2 : RUNOFF WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
CONTROL PLOT 2	JUNE 1981	3	120	7.8	1.0	150	2.5	3.8	N.D	32
	JULY 1981	10	61	7.8	1.4	910	1.7	2.8	N.D	7
	AUG 1981	10	92	7.4	5.0	1850	0.662	0.4	N.D	2.0
	SEPT 1981	5	10	7.91	0.75	460	0.417	0.41	N.D	5.0
	OCT 1981	3	29	7.6	1.0	305	0.638	2.46	N.D	6.0
	MAY 1982	2	75	7.6	1.5	100	11.6	2.96	N.D	10.0
	JUNE 1982	5	200	7.9	1.5	100	2.39	3.80	N.D	73
	JULY 1982	5	50	7.2	0.2	350	0.72	3.52	N.D	12
	AUG 1982	3	30	7.2	1.0	410	0.6	2.2	N.D	9
	SEPT 1982	6	52	7.2	1.5	150	0.919	2.04	N.D	5.0

APPENDIX 2 : RUNOFF WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
FRESH PLOT 1	JUNE 1981	14	350	7.72	5.8	510	9.86	5.83	N.D	132
	JULY 1981	21	500	8.30	7.4	1000	11.5	19.3	N.D	391
	AUG 1981	20	140	7.4	3.0	680	10.8	11.4	N.D	268
	SEPT 1981	12	248	8.03	2.5	1400	4.85	6.28	N.D	119
	OCT 1981	6	290	8.0	1.3	1150	5.7	8.7	N.D	180
	MAY 1982	3	295	8.1	4	850	9.5	11.1	N.D	215
	JUNE 1982	13	550	8.1	5	1100	13.6	13.9	N.D	300
	JULY 1982	13	120	8.3	3	600	8.35	7.98	N.D	144
	AUG 1982	10	120	8.0	8	850	9.79	11.7	N.D	156
	SEPT 1982	18	340	7.9	LT .1	800	6.34	11.0	N.D	238

APPENDIX 2 : RUNOFF WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
FRESH PLOT 2	JUNE 1981	14	260	8.34	2.2	500	8.35	11.7	N.D	223
	JULY 1981	21	190	7.8	4.5	1330	6.5	7.0	N.D	208
	AUG 1981	20	132	7.4	3.5	2600	4.28	2.83	N.D	37
	SEPT 1981	12	456	8.03	1.5	1060	4.93	7.2	N.D	138
	OCT 1981	6	423	7.5	1.8	1910	6.31	8.3	N.D	185
	MAY 1982	3	395	8.0	4.5	1000	9.7	11.0	N.D	250
	JUNE 1982	13	780	7.8	8	1300	16.8	15.8	N.D	342
	JULY 1982	13	150	8.0	6	850	7.45	7.28	N.D	200
	AUG 1982	10	220	8.0	2.5	1000	6.79	10.4	N.D	223
	SEPT 1982	18	370	8.0	2.0	850	7.89	9.54	N.D	223

APPENDIX 2 : RUNOFF WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
STORED PLOT 1	JUNE 1981	5	410	7.74	5.25	520	8.39	13.6	N.D	212
	JULY 1981	16	420	8.26	4.75	840	9.33	18.2	N.D	305
	AUG 1981	16	285	7.2	3.0	920	4.85	2.0	N.D	16
	SEPT 1981	8	288	7.97	1	780	7.29	4.84	N.D	91
	OCT 1981	7	305	8.1	1.0	745	7.91	6.42	N.D	75
	MAY 1982	3	206	8.1	6	750	11.2	8.3	N.D.	105
	JUNE 1983	10	180	8.1	11	600	14.6	8.62	N.D	116
	JULY 1982	7	84	8.2	9	900	11.7	6.72	N.D	68
	AUG 1982	7	220	7.9	5.0	750	9.86	9.59	N.D	180
	SEPT 1982	13	330	8.4	1.0	700	8.45	8.2	N.D	58

APPENDIX 2 : RUNOFF WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/1)	TOTAL SOLIDS (mg/1)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
STORED PLOT 2	JUNE 1981	5	240	8.0	3.2	660	6.2	7.5	N.D	107
	JULY 1981	16	92	8.0	3.6	900	7.0	6.1	N.D	85
	AUG 1981	16	75	7.3	5.5	1300	2.74	1.16	N.D	17
	SEPT 1981	8	410	8.0	1.3	1060	5.69	5.14	N.D	106
	OCT 1981	7	237	7.6	0.5	630	6.35	4.80	N.D	79
	MAY 1982	3	168	7.8	2	600	7.10	7.18	N.D	107
	JUNE 1982	10	280	8.0	3	600	4.75	7.65	N.D	111
	JULY 1982	7	160	8.2	3	800	9.06	7.07	N.D	101
	AUG 1982	7	170	7.9	1	700	7.10	9.31	N.D	150
	SEPT 1982	13	44	7.14	LT .1	200	7.31	4.41	N.D	51

APPENDIX 3 : DRAINAGE WATER QUALITY

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
CONTROL PLOT 1	AUG 1981	4	7.2	7.1	1.0	520	0.36	0.999	2	7
	SEPT 1981	4	8	6.97	0.3	370	0.41	0.82	3	8
	JULY 1982	1	29	6.7	0.8	460	0.4	0.85	3	7
	SEPT 1982	1	71	6.77	1.0	500	0.429	0.728	4	9
CONTROL PLOT 2	AUG 1981	4	30	6.66	1.3	650	0.07	0.385	3	5
	SEPT 1981	4	17	6.83	0.2	880	0.06	0.36	2	6
	JULY 1982	1	50	6.8	0.7	630	0.07	0.36	6	10
	SEPT 1982	1	110	6.85	0.6	350	0.067	0.343	5	10

APPENDIX 3 : DRAINAGE WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
FRESH PLOT 1	AUG 1981	5	16	7.61	0.5	1830	0.732	9.62	18	23
	SEPT 1981	5	76	6.72	3.0	1260	0.9	6.60	72	77
	JULY 1982	1	35	6.9	1.5	1350	0.88	7.09	63	71
	SEPT 1982	1	15	6.2	1.0	950	0.991	5.04	59	64
FRESH PLOT 2	AUG 1981	5	188	6.92	0.4	2560	0.274	0	41	50
	SEPT 1981	5	64	6.37	1.4	690	0.5	1.05	68	74
	JULY 1982	1	85	6.7	1.1	1830	0.49	0.65	63	70
	SEPT 1982	1	35	6.9	1.6	2250	0.609	0.871	52	57

APPENDIX 3 : DRAINAGE WATER QUALITY (CONT'D)

TREATMENT	DATE	NUMBER SAMPLES POOLED	BIOCHEMICAL OXYGEN DEMAND	pH	SETTLEABLE SOLIDS (mg/l)	TOTAL SOLIDS (mg/l)	P (ppm)	K (ppm)	$N(NO_3)$ (ppm)	N(total) (ppm)
STORED PLOT 1	AUG 1981	4	194	7.55	0.7	1520	0.931	1.81	26	35
	SEPT 1981	4	51	7.98	1.2	420	1.15	1.65	15	17
	JULY 1982	1	75	7.7	1.6	1280	1.15	1.68	12	16
	SEPT 1982	1	62	7.7	3.0	1900	1.38	1.57	9	12
STORED PLOT 2	AUG 1981	4	121	6.9	0.6	330	0.662	0.814	20	25
	SEPT 1981	4	23	6.95	0.8	360	0.93	1.31	15	23
	JULY 1982	1	85	7.0	0.8	510	0.88	1.23	15	22
	SEPT 1982	1	110	7.23	2.0	850	1.06	1.56	10	19

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981

WEEK NO	RAINFALL (mm)	EVAPORATION (mm)	EVAPO-TRANSPIRATION (mm) (calc.)	CONTROL STORAGE (mm) (calc.)	RUNOFF (mm) PREDICTED	RUNOFF (mm) ACTUAL CONTROL-1	RUNOFF (mm) ACTUAL CONTROL-2
1	4	55	18	36	0	0	0
2	8	53	18	26	0	0	0
3	12	50	18	20	0	0	0
4	0	61	24	3	0	0	0
5	0	60	25	0	0	0	0
6	12	44	19	3	0	0	0
7	1	45	20	1	0	0	0
8	6	43	21	1	0	0	0
9	41	34	17	25	0	0	0
10	5	33	17	22	0	0	0
11	10	29	16	23	0	0	0
12	7	32	19	21	0	0	0
13	3	19	12	19	0	0	0
14	12	20	13	23	0	0	0
15	1	23	15	19	0	0	0
16	9	22	15	20	0	0	0
17	17	15	11	27	0	0	0
18	2	11	8	26	0	0	0
19	5	11	8	26	0	0	0
20	4	8	6	27	0	0	0
21	1	7	6	25	0	0	0
22	46	9	7	64	0	0	0
23	2	6	5	62	0	0	0
24	8	3	2	68	0	0	0
25	28	6	5	91	0	0	1
26	20	4	3	97	9	0	0

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981 (CONT'D)

WEEK NO	RAINFALL (mm)	EVAPORATION (mm)	EVAPO-TRANSPIRATION (mm) (calc.)	STORAGE (mm) (calc.)	CONTROL RUNOFF (mm) PREDICTED	ACTUAL CONTROL-1	ACTUAL CONTROL-2
27	21	8	6	94	15	3	3
28	10	4	3	97	3	0	0
29	20	3	2	98	14	1	1
30	32	11	9	91	25	9	12
31	17	8	6	94	7	5	0
32	19	8	6	94	11	4	3
33	40	11	9	91	28	26	31
34	17	9	7	93	7	8	1
35	16	12	10	90	7	7	5
36	1	18	14	77	0	0	0
37	4	20	16	65	0	0	0
38	28	22	18	75	1	1	2
39	3	22	18	61	0	0	0
40	34	26	21	74	4	5	6
41	5	27	20	60	0	0	0
42	5	23	16	52	0	0	0
43	14	34	23	47	0	0	0
44	6	34	22	38	0	0	0
45	16	26	15	42	0	0	0
46	2	28	15	35	0	0	0
47	7	33	17	32	0	0	0
48	3	38	18	26	0	0	0
49	3	39	17	22	0	0	0
50	14	45	17	19	0	0	0
51	0	50	17	8	0	0	0
52	3	50	15	4	0	0	0

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981 (CONT'D)

WEEK	FRESH PLOT 1				FRESH PLOT 2			
			RUNOFF				RUNOFF	
NUMBER	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)
1	11	47	0	0	11	47	0	0
2	12	49	0	0	12	49	0	0
3	11	54	0	0	5	48	0	0
4	3	33	0	0	8	32	0	0
5	11	19	0	0	9	16	0	0
6	12	24	0	0	8	18	0	0
7	11	16	0	0	8	11	0	0
8	3	9	0	0	7	8	0	0
9	10	43	0	0	8	40	0	0
10	9	45	0	0	8	40	0	0
11	13	53	0	0	8	45	0	0
12	8	52	0	0	4	42	0	0
13	4	49	0	0	10	45	0	0
14	8	57	0	0	7	52	0	0
15	13	58	0	0	8	49	0	0
16	7	60	0	0	8	53	0	0
17	6	72	0	0	12	71	0	0
18	13	79	0	0	19	84	0	0
19	7	83	0	0	8	89	0	0
20	7	88	0	0	11	94	0	0
21	13	94	0	0	13	94	0	0
22	12	93	0	3	4	93	0	1
23	14	95	9	1	13	95	8	2
24	7	98	10	9	12	98	15	2
25	15	95	21	17	12	95	18	10
26	16	97	31	18	7	97	22	19

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981 (CONT'D)

WEEK	FRESH PLOT 1				FRESH PLOT 2			
			RUNOFF				RUNOFF	
NUMBER	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)
27	12	94	30	17	13	94	31	23
28	7	97	11	11	16	97	20	10
29	15	98	32	22	12	98	29	19
30	14	91	44	43	13	91	43	49
31	18	94	26	20	8	94	16	25
32	9	94	22	18	18	94	31	28
33	6	91	40	58	14	91	48	72
34	15	93	23	16	14	93	22	11
35	11	90	20	16	5	90	14	17
36	12	86	3	2	11	86	2	3
37	6	80	0	3	11	84	1	2
38	11	82	19	6	10	82	22	7
39	9	76	0	2	9	76	0	5
40	17	79	27	19	14	79	24	22
41	12	76	0	1	5	69	0	2
42	4	69	0	0	8	67	0	1
43	7	67	0	0	7	65	0	0
44	5	58	0	0	6	57	0	0
45	6	66	0	0	4	63	0	0
46	9	63	0	0	10	61	0	0
47	11	65	0	0	12	64	0	0
48	11	62	0	0	6	57	0	0
49	7	57	0	0	13	58	0	0
50	5	49	0	0	8	63	0	0
51	7	39	0	0	10	56	0	0
52	7	34	0	0	5	49	0	0

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981 (CONT'D)

WEEK	STORED PLOT 1				STORED PLOT 2			
			RUNOFF				RUNOFF	
NUMBER	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)
1	5	41	0	0	11	48	0	0
2	12	43	0	0	6	44	0	0
3	13	50	0	0	14	52	0	0
4	13	39	0	0	11	39	0	0
5	5	19	0	0	11	25	0	0
6	14	26	0	0	10	28	0	0
7	16	23	0	0	11	20	0	0
8	7	15	0	0	9	15	0	0
9	5	44	0	0	8	47	0	0
10	8	44	0	0	4	43	0	0
11	4	45	0	0	11	50	0	0
12	10	46	0	0	10	51	0	0
13	5	45	0	0	8	52	0	0
14	4	50	0	0	7	59	0	0
15	8	47	0	0	4	52	0	0
16	11	53	0	0	0	49	0	0
17	17	76	0	0	13	68	0	0
18	5	75	0	0	7	69	0	0
19	14	86	0	0	14	80	0	0
20	4	94	0	0	11	89	0	0
21	5	94	0	0	10	94	0	0
22	7	93	0	0	3	93	0	1
23	2	92	0	0	15	95	8	0
24	4	98	3	0	5	98	7	0
25	4	95	5	3	2	95	4	3
26	4	97	16	6	4	97	16	4

APPENDIX 4 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1981 (CONT'D)

WEEK	STORED PLOT 1				STORED PLOT 2			
			RUNOFF				RUNOFF	
NUMBER	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	PREDICTED (mm)	ACTUAL (mm)
27	2	94	17	9	4	94	18	6
28	4	97	7	3	4	97	7	3
29	4	98	17	9	2	98	16	14
30	4	91	28	31	4	91	28	18
31	4	94	10	0	4	94	10	6
32	3	90	0	12	4	94	14	9
33	4	91	28	48	4	91	32	38
34	4	93	10	5	2	93	8	5
35	4	90	11	11	4	90	11	13
36	2	79	0	2	4	81	0	1
37	4	71	0	1	4	73	0	0
38	4	82	2	4	2	82	2	3
39	4	71	0	0	12	79	0	0
40	11	79	13	19	6	79	16	13
41	11	75	0	5	11	75	0	1
42	8	72	0	0	8	72	0	0
43	3	66	0	0	8	71	0	0
44	10	61	0	0	5	61	0	0
45	7	69	0	0	7	69	0	0
46	5	62	0	0	7	64	0	0
47	10	63	0	0	5	60	0	0
48	14	63	0	0	14	58	0	0
49	29	73	0	0	20	65	0	0
50	23	79	0	0	23	83	0	0
51	23	83	0	0	25	83	0	0
52	25	85	0	0	18	85	0	0

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982

WEEK NO	RAINFALL (mm)	EVAPORATION (mm)	EVAPO-TRANSPIRATION (mm) (calc.)	STORAGE (mm) (calc.)	CONTROL RUNOFF (mm) PREDICTED	ACTUAL CONTROL-1	ACTUAL CONTROL-2
1	18	43	14	54	0	0	0
2	0	50	17	37	0	0	0
3	6	47	17	26	0	0	0
4	2	40	16	13	0	0	0
5	0	54	22	2	0	0	0
6	0	53	23	0	0	0	0
7	0	56	26	0	0	0	0
8	11	42	20	2	0	0	0
9	0	36	18	2	0	0	0
10	10	30	16	6	0	0	0
11	3	26	14	6	0	0	0
12	10	33	19	9	0	0	0
13	30	30	18	23	0	0	0
14	8	24	15	23	0	0	0
15	3	17	11	21	0	0	0
16	4	15	10	21	0	0	0
17	42	11	8	55	0	1	1
18	25	12	9	71	0	0	0
19	6	12	9	68	0	0	0
20	7	11	9	67	0	0	0
21	0	8	6	62	0	0	0
22	3	8	6	60	0	0	0
23	0	5	4	57	0	0	0
24	21	5	4	74	0	0	0
25	17	5	4	87	0	0	0
26	12	6	5	94	0	0	0

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982 (CONT'D)

WEEK NO	RAINFALL (mm)	EVAPORATION (mm)	EVAPO-TRANSPIRATION (mm) (calc.)	CONTROL STORAGE (mm) (calc.)	CONTROL RUNOFF (mm) PREDICTED	CONTROL RUNOFF (mm) ACTUAL CONTROL-1	CONTROL RUNOFF (mm) ACTUAL CONTROL-2
27	14	5	4	96	4	4	3
28	2	5	4	94	0	0	0
29	1	3	2	93	0	0	0
30	16	8	6	94	4	2	2
31	2	10	8	88	0	0	0
32	4	8	6	86	0	0	0
33	5	9	7	84	0	0	0
34	1	15	12	73	0	0	0
35	27	16	13	87	0	0	0
36	24	17	14	86	5	3	2
37	11	12	10	87	0	0	0
38	1	21	17	71	0	0	0
39	0	21	17	56	0	0	0
40	0	27	22	41	0	0	0
41	0	30	23	29	0	0	0
42	11	22	16	30	0	0	0
43	3	31	21	24	0	0	0
44	7	34	22	21	0	0	0
45	3	45	27	3	0	0	0
46	11	41	23	3	0	0	0
47	0	53	27	0	0	0	0
48	1	47	22	0	0	0	0
49	70	37	16	54	0	0	0
50	0	50	19	35	0	0	0
51	0	49	17	18	0	0	0
52	1	50	15	9	0	0	0

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982 (CONT'D)

WEEK	FRESH PLOT 1				FRESH PLOT 2			
NUMBER	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)
1	9	43	0	0	12	66	0	0
2	11	37	0	0	15	64	0	0
3	16	42	0	0	13	66	0	0
4	12	40	0	0	5	57	0	0
5	9	27	0	0	15	50	0	0
6	13	17	0	0	15	42	0	0
7	16	10	0	0	14	30	0	0
8	14	17	0	0	7	28	0	0
9	9	18	0	0	13	29	0	0
10	13	28	0	0	15	39	0	0
11	17	36	0	0	16	46	0	0
12	22	50	0	0	7	47	0	0
13	18	45	0	4	11	70	0	0
14	19	57	0	0	14	77	0	0
15	12	62	0	0	13	82	0	0
16	14	70	0	0	6	82	0	0
17	9	92	3	5	16	92	5	2
18	14	91	5	5	13	91	5	2
19	18	91	7	1	8	91	2	1
20	9	91	3	6	14	91	5	2
21	20	94	5	2	17	94	4	6
22	2	91	0	4	13	94	5	4
23	7	94	0	4	24	96	8	6
24	15	96	14	19	9	96	12	12
25	16	96	13	9	13	96	12	13
26	6	95	6	6	16	95	11	14

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982 (CONT'D)

WEEK NUMBER	FRESH PLOT 1				FRESH PLOT 2			
	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)
27	14	96	10	3	17	96	12	13
28	15	96	6	1	7	96	2	9
29	17	98	6	2	13	98	5	4
30	7	94	10	5	12	94	12	13
31	19	92	7	0	12	92	4	5
32	10	94	3	3	12	94	4	0
33	13	93	5	10	6	93	2	6
34	10	88	2	0	9	88	1	3
35	5	87	9	13	11	87	12	14
36	8	86	9	17	8	86	9	16
37	7	90	2	1	5	90	1	6
38	7	81	0	1	8	82	0	2
39	6	70	0	0	4	69	0	0
40	8	57	0	0	6	55	0	0
41	10	48	0	0	4	42	0	0
42	4	49	0	0	7	47	0	0
43	9	45	0	0	13	46	0	0
44	10	44	0	0	12	47	0	0
45	10	30	0	0	7	30	0	0
46	5	23	0	0	13	31	0	0
47	14	10	0	0	13	17	0	0
48	11	7	0	0	12	11	0	0
49	12	73	0	0	7	72	0	0
50	5	59	0	0	13	66	0	0
51	10	52	0	0	6	55	0	0
52	6	44	0	0	11	52	0	0

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982 (CONT'D)

WEEK NUMBER	STORED PLOT 1				STORED PLOT 2			
	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF		EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF	
			PREDICTED (mm)	ACTUAL (mm)			PREDICTED (mm)	ACTUAL (mm)
1	21	75	0	0	34	86	0	0
2	15	62	0	0	23	83	0	0
3	17	68	0	0	7	79	0	0
4	13	67	0	0	13	78	0	0
5	14	59	0	0	12	68	0	0
6	8	44	0	0	16	61	0	0
7	21	39	0	0	6	41	0	0
8	20	50	0	0	15	47	0	0
9	13	48	0	0	17	49	0	0
10	7	51	0	0	15	59	0	0
11	15	56	0	0	5	55	0	0
12	13	61	0	0	14	61	0	0
13	15	82	0	0	14	82	0	0
14	8	83	0	0	5	80	0	0
15	13	88	0	1	5	77	0	0
16	14	90	0	0	12	83	0	0
17	12	92	10	6	14	92	9	5
18	7	91	5	3	17	91	8	5
19	14	91	5	8	8	91	2	2
20	15	91	6	0	15	91	6	2
21	16	94	3	8	0	85	0	0
22	2	93	0	0	25	94	6	6
23	2	91	0	0	5	95	0	0
24	4	96	7	0	5	96	10	2
25	2	96	7	4	4	96	8	2
26	4	95	5	0	4	95	5	2

APPENDIX 5 : HYDROLOGICAL STUDIES OF THE EXPERIMENTAL PLOTS-1982 (CONT'D)

WEEK NUMBER	STORED PLOT 1				STORED PLOT 2			
	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)	EFFLUENT APPLIED (mm)	STORAGE (mm)	RUNOFF PREDICTED (mm)	RUNOFF ACTUAL (mm)
27	4	96	6	4	3	96	5	5
28	4	96	1	0	4	96	1	1
29	2	97	0	0	4	98	0	0
30	4	94	8	2	4	94	8	8
31	2	90	0	0	5	92	0	1
32	4	92	0	2	2	92	0	1
33	4	93	0	0	4	93	0	1
34	2	84	0	0	4	86	0	0
35	4	87	7	7	4	87	8	3
36	2	86	6	12	2	86	6	7
37	4	90	0	1	4	90	0	0
38	2	76	0	2	4	78	0	1
39	4	63	0	0	6	67	0	0
40	7	51	0	0	5	53	0	0
41	7	41	0	0	7	43	0	0
42	10	48	0	0	9	49	0	0
43	2	39	0	0	13	48	0	0
44	9	39	0	0	5	43	0	0
45	24	39	0	0	24	43	0	0
46	37	64	0	0	35	66	0	0
47	18	55	0	0	35	73	0	0
48	25	59	0	0	22	74	0	0
49	21	84	0	0	26	84	0	0
50	13	78	0	0	9	74	0	0
51	7	68	0	0	5	62	0	0
52	15	69	0	0	11	59	0	0

APPENDIX 6 : STANDARD WEEKLY PERIODS

WEEK NO.	DATE	WEEK NO.	DATE
1	Jan 01 - Jan 07	27	Jul 02 - Jul 08
2	Jan 08 - Jan 14	28	Jul 09 - Jul 15
3	Jan 15 - Jan 21	29	Jul 16 - Jul 22
4	Jan 22 - Jan 28	30**	Jul 23 - Jul 30
5	Jan 29 - Feb 04	31	Jul 31 - Aug 06
6	Feb 05 - Feb 11	32	Aug 07 - Aug 13
7	Feb 12 - Feb 18	33	Aug 14 - Aug 20
8	Feb 19 - Feb 25	34	Aug 21 - Aug 27
9*	Feb 26 - Mar 04	35	Aug 28 - Sep 03
10	Mar 05 - Mar 11	36	Sep 04 - Sep 10
11	Mar 12 - Mar 18	37	Sep 11 - Sep 17
12	Mar 19 - Mar 25	38	Sep 18 - Sep 24
13	Mar 26 - Apr 01	39	Sep 25 - Oct 01
14	Apr 02 - Apr 08	40	Oct 02 - Oct 08
15	Apr 09 - Apr 15	41	Oct 09 - Oct 15
16	Apr 16 - Apr 22	42	Oct 16 - Oct 22
17	Apr 23 - Apr 29	43	Oct 23 - Oct 29
18	Apr 30 - May 06	44	Oct 30 - Nov 05
19	May 07 - May 13	45	Nov 06 - Nov 12
20	May 14 - May 20	46	Nov 13 - Nov 19
21	May 21 - May 27	47	Nov 20 - Nov 26
22	May 28 - Jun 03	48	Nov 27 - Dec 03
23	Jun 04 - Jun 10	49	Dec 04 - Dec 10
24	Jun 11 - Jun 17	50	Dec 11 - Dec 17
25	Jun 18 - Jun 24	51	Dec 18 - Dec 24
26	Jun 25 - Jul 01	52	Dec 25 - Dec 31

* week 09 has 8 days in each leap year

** week 30 has 8 days every year